ELEMENTARY BIOLOGY

M. E. PHILLIPS & L. E. COX

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WITH NUMEROUS DIAGRAMS

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PREFACE

Many leading authorities have recently made suggestions as to the scope of an elementary course in Biology. In this textbook we have given full consideration to their views.

We hope the book may prove useful, not only when Biology is part of an examination course, but also in those schools in which it is studied as a cultural subject.

The types selected are treated with exactitude and in some detail. Scientific terms for which there are no simple equivalents have not been avoided; one such term frequently obviates a wordy explanation, and familiarity with the vocabulary is essential if the study of the subject is to be carried further.

We wish to thank the authors, editors, and publishers of the following works for permission to reproduce figures: *Practical Plant Physiology*, by Sir Frederick Keeble (George Bell & Sons), for Fig. 266; *Lessons on Soil*, by Sir John Russell (Cambridge University Press), for Fig. 267; *Elements of General Zoology*, by Professor W. J. Dakin (Oxford University Press), for Fig. 71; *Proceedings of the Zoological Society of London*, 1907, Monograph by Baron Nopsca, for Fig. 60; F. W. Pycraft, Esq., for Fig. 61; and Messrs. Heinemann for Fig. 69 (after Marey).

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SECTION I

SIMPLE LIVING FORMS OF INCREASING COMPLEXITY

INTRODUCTORY

"The Present is the Child of the Past and the Parent of the Future."

This quotation gives the key-note of the development of living things. It states concisely that all individuals living at this present time have a long line of ancestry behind them, and that they, in their turn, will be the ancestors of future generations.

The solid earth on which these individuals live and move has itself a past history. The most commonly accepted view of the earth's beginning is that it was forcibly separated off from the sun, in vaporous masses called nebulæ. Many of these came together by the force of mutual attraction, forming, among other planets, our earth.

The mass that we call "earth" cooled and contracted, and in the furrows thus formed, after long ages, water collected, and in these cooling waters life began.

The primitive forms of life must have been extremely simple. A knowledge of the simplest living creatures of our own times gives a basis for speculating as to the nature of the individuals that were first created, and so became the ancestors of us all.

The great probability is that they closely resembled the bacteria that play so important a part in the world to-day. These *Protists*, as they are called, probably lived by making use of the surrounding air and water and of the salts dissolved in the water. Probably they gave rise, eventually, to other one-celled organisms, more advanced than the Protists, which contained chlorophyll, and by its means built up their food from inorganic substances. These later individuals probably closely resembled the Chlamydomonas of to-day and were the founders of the whole Kingdom of the Plants.

Side by side with these there evolved, in all probability, another line of one-celled organisms that did not contain chlorophyll, and, because of this lack, were not able to manufacture food, and lived therefore by devouring their neighbours.

The probability is that this second line of primitive individuals closely resembled the Amœba of our times. In these primitive beings we have, doubtless, the founders of the Animal Kingdom.

CHAPTER I

AMŒBA

Amœba, like Chlamydomonas, is a cell. Unlike Chlamydomonas it is a cell that is not bounded by a wall. As a matter of fact, the term " cell " for these units of plant and animal life is not a particularly good one. It was given under a misapprehension, more than two hundred years ago, and has remained in biological terminology from that time onward.

The Cell.

In the seventeenth century plant tissues were, for the first time, examined under magnifying lenses. The botanists of that period were struck by their close superficial resemblance to the massed cells of a honey-comb. They concluded that the importance of the tissues centred in the boundary walls of the cavities they observed, and they called these cavities " cells."

Actually it is the living contents of the cell, the protoplasm with its nucleus, that are all-important.

In the nineteenth century Prof. Huxley defined protoplasm as " the physical basis of life." Life, in other words, manifests itself through the medium of protoplasm. It is the living part of all organisms, whether these be plant or animal. Every individual begins its life as a *cell* ; that is to say, as a minute speck of protoplasm with its attendant nucleus.

Chemical analysis has shown that protoplasm is composed of carbon, hydrogen, oxygen, nitrogen, and sulphur, with varying and minute amounts of phosphorus and other elements. The process of analysis, however, kills the protoplasm subjected to it, and, as the outstanding quality of protoplasm is the fact that it *lives*, a mere knowledge of the elements that compose it brings us but little nearer to an understanding of its fundamental structure.

The Nucleus.

The general protoplasm of the cell is the *cytoplasm*. Within this is a rounder, denser, more deeply staining body, bounded by a thin membrane. This is the *nucleus*, which controls and directs all the activities of the cell.

There are various species of Amœba : some live in soil ; others in salt water ; others in the blood and alimentary canal of man. Others again, and these perhaps the greatest number, make the mud of ponds and ditches their habitat. But even here they are certainly not nearly so numerous as many textbooks lead one to suppose.

The different species of Amœba vary greatly in size. The largest, once its position on a slide is known, can just be detected by the naked eye. This is *Amœba proteus*, which measures $\frac{1}{75}$ inch in diameter.

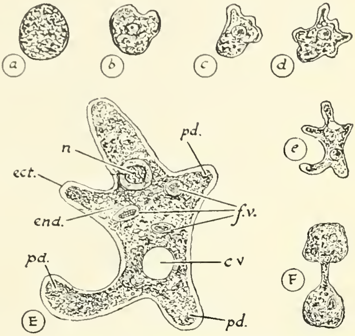


Fig. 1.—*a–e*, diagrams of an encysted Amœba, gently warmed by holding the slide on the warmed hand. Its successive movements were then noted and drawn. E is *e* highly magnified. *c.v.*, contractile vacuole; *ect.*, ectoplasm; *end.*, endoplasm; *f.v.*, food vacuoles with ingested particles; *n.*, nucleus; *pd.*, pseudopodia. F shows binary fission.

The name of "this fascinating bit of protoplasm," as Prof. Calkins calls it, comes from the Greek word *amoibë*, which means *change*. The reason is clear when a living Amœba is studied under the microscope. One draws a more or less roundish blob with unequal projections. After a certain interval has elapsed the drawing and the "drawn" do not tally. The Amœba has "changed." This change is not one of mere movement, but frequently of movement in a forward direction (Fig. 1, *a–e*).

Morphology.

From the point of view of *morphology*, that is the study of its *form*, Amœba is very simple. The protoplasm is paler and clearer on the outside, and is called the *ectoplasm*. The greater bulk is granular in character, and is called the *endoplasm* (Fig. 1, E).

Contraction.

Movement is caused by a projection of the ectoplasm, followed by a flow of endoplasm in the same direction. Such a projection is termed a *pseudopodium*, or *false foot*. Several pseudopodia may be projected simultaneously, but usually one takes the lead in activity. By the time the whole of the endoplasm has flowed in one direction into the projection, the Amœba has moved a distance equal to its length as first noted.

The contraction of the protoplasm of this single cell is comparable with the muscular contraction of the higher animals.

Respiration. Indirectly it may be proved that Amœba breathes. When Amœbæ are transferred to water that has been boiled to get rid of oxygen, then allowed to cool, the characteristic movements of the animals cease. They are not respiring, and therefore there is no liberation of energy (p. 172). If they remain in this environment the cells disintegrate.

Discrimination. There is no mouth-part in Amœba. The food is ingested in solid form by the protoplasm. And here the animal exercises a certain selective power. Not only does it disregard particles of sand placed in its path, but it acts positively in moving away from them. This is not the only manifestation of its *sensitiveness*, that is, its reaction to the outside world. Certain responsive movements are also made by it in relation to light and heat.

Assimilation. When Amœba comes in contact with an organic body suitable for food, such as a unicellular plant or animal, even another Amœba smaller than itself, this is engulfed. The moving protoplasm presses upon it, and, at each movement, the captive becomes more deeply involved in the body of the captor.

In the endoplasm the ingested food particle is seen surrounded by a spherical fluid area, known as the *food-vacuole* (Fig. 1, E). The particle within the fluid slowly loses its form. It is actually being digested by the fluid of the vacuole. This has been shown to be acid in character. Probably, too, it contains something in the nature of an enzyme (p. 153). The digestive process is therefore comparable with that which takes place in the stomach of a mammal (p. 155). When the process is complete the digested food diffuses through the whole body of the animal.

Growth. As a result of the intake of food the individual Amœba grows to a certain definitive size. The elements of the absorbed food are being added to the molecules of protoplasm, that is, they are being actually incorporated into the substance of the protoplasm. In this way the loss resulting from the output of energy, from breathing and from secretion, is made good.

Secretion.

For Amœba actively secretes. Like Chlamydomonas (p. 11), it has a *contractile vacuole* (Fig. 1, E). This is a clear-looking area which, under high magnification, is seen to increase slowly in size. This is due to liquid being drained into it, along minute channels, from the surrounding protoplasm. The emptying, or collapse, of the vacuole is sudden. It is claimed that the presence of crystals of uric acid has been demonstrated in the fluid of the vacuole. In the higher animals it is by the discharge of urea from the kidneys that nitrogenous waste is ejected from the body.

Adaptation.

By subjecting Amœba to changed conditions in its environment it may, up to a certain limit, be "educated," or trained. If an Amœba, living in fresh water, be transferred to a medium that is very slightly salt, it lives healthily in this changed habitat. After repeated gradual increases in the amount of salt added the Amœba, and its descendants too, live in the brackish water, carrying out all their normal functions.

The Amœba has been "trained" to live in this new environment. A sudden change from fresh to brackish water would have resulted in the death of the individual.

Similarly Amœbæ may be trained to live in water of a higher temperature than that of the normal habitat.

Reproduction.

The descendants of Amœbæ are very simply produced. The nucleus, which is embedded in the endoplasm, lengthens considerably and becomes constricted in the middle. The cytoplasm accommodates itself to the changed shape of the nucleus, so that the animal is dumb-bell-shaped. Finally there is an actual break at the constriction. This results in the separation of two independent daughter-Amœbæ, each with its own nucleus and cytoplasm (Fig. 1, F).

The term *daughter*-Amœba is convenient, but perhaps not very good, because after the cleavage no parent remains, nor are the resulting offspring of any one sex.

This extremely simple method of reproduction is known as *binary fission.*

Encystment.

Under adverse conditions—cold, drought, scarcity of food—Amœba withdraws all pseudopodia and, rounding itself off, invests itself with a tough covering. Very often in tubes of Amœbæ bought for study in the laboratory, the animals are found to be in this *encysted* state. If the tube is put for a short time in tepid water, they will resume their normal amœboid mode of life.

As cysts the animals can persist for a very long time, and, in this condition, are often blown with the dried mud of the pond to some new habitat.

Nuclear Control.

Delicate operations have been performed on Amœbæ to show the importance of the nucleus in the life of the cell. Individuals have been cut in such a way that one half is nucleated, while the other is cytoplasm merely.

The nucleated part has lived quite normally, moving, feeding, and reproducing.

The non-nucleated part has been known to live for, at any rate, a month. At least it has, so to speak, " remained." It has absorbed no nourishment, and all response to stimulus has ceased. In the ordinary way, if an Amœba is touched with a very fine point, the pseudopodium in the neighbourhood of the prick is withdrawn. No such withdrawal follows the prick of the non-nucleated individual, which finally disintegrates, or dies.

Physiology.

Within the very narrow limits of a single cell Amœba carries out the physiological functions that, in the higher animals, are relegated to specialised organs of the body.

Movement and *muscular activity* are carried out by the general protoplasm. *Respiration* also is the work of the cell as a whole. The cell exercises a *selective power* in feeding, although there are no specialised sense organs. *Digestion* follows feeding, the cell functioning at the same time as a stomach and as a digestive gland. As a result of feeding there is *growth* of the cell until a certain definitive size is reached. At this point the life of the Amœba culminates in its power of *reproduction* ; it is capable of giving rise to new individuals, thus providing for the maintenance of the race.

PRACTICAL WORK

General Note.

Throughout the course, in plant-work and animal-work alike, accurate drawings, fully named, should be made in special exercise books that have plain pages of good quality.

These books then provide a complete record of the practical work done during the course.

Amœba.

Living Amœbæ should be mounted in water on a slide and examined under the microscope. Examination of a prepared slide is recommended for noting details of structure.

CHAPTER II

CHLAMYDOMONAS

Chlamydomonas is a minute, free-swimming, green, one-celled plant that is common in pools and rain-water tanks. It can be found in abundance in the spring and summer months.

Unfortunately its very small size, coupled with its active movements, make it difficult to investigate under the ordinary school microscope. It is thus often a disappointing object of study for the beginner. Its great interest lies in the fact that it is one of the most primitive plants at present existing.

As in the case of Amœba all the vital activities are carried out by one cell. There is no specialisation ; no division of labour. Food materials are taken in ; food is built up ; waste liquid is got rid of ; respiration is effected ; protection is provided for ; movement is carried on ; reproduction is finally achieved. And all this within the limits of one tiny cell.

General Structure.

Structurally Chlamydomonas differs from Amœba in many important points. The organism is somewhat pear-shaped, the more pointed being the front, or anterior, end (Fig. 2). It is bounded by a wall composed of the carbohydrate *cellulose*, the substance of which the walls of all young plant cells are made.

Within the cell wall is the living substance, or protoplasm. Embedded in the protoplasm is a large basin-shaped green body, termed the *chromatophore*. This body is so large as to fill up the lower three-quarters of the cell. The chromatophore is made up of a proteid substance like protoplasm ; its colour is due to a green substance, *chlorophyll*, which is dissolved in it.

It is due to chlorophyll that green plants are able to feed on simple inorganic substances. The plant takes in water and the carbon dioxide dissolved in it. From these substances, by means of energy which chlorophyll can absorb directly from the sun's rays, it is able to build up the carbohydrate, sugar ; from this starch is formed (p. 309).

It is thus evident that the earliest living things, which were of necessity self-supporting, must have possessed either chlorophyll or some other similar substance.

In the lower part of the basin-shaped chromatophore is a conspicuous object termed the *pyrenoid*. When the cell is treated with iodine this becomes darkly blue-black. It is thus revealed as the centre of the starch-making activity. Lying in the protoplasm, in the hollow of the basin, is the cell nucleus. This is extremely difficult to see, as it is surrounded on all sides by the green chromatophore. Near the forward end of the chromatophore, lying close to its outward side, is a bright red spot, the *eye-spot*. The red colour is due to a substance termed *carotin*, the same red pigment that occurs in the carrot. It can be proved that Chlamydomonas is sensitive to the direction of light. Possibly the eye-spot foreshadows the line of evolution which culminated in the visual eye.

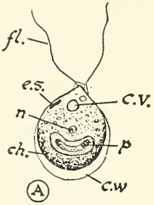


FIG. 2.—Chlamydomonas. *ch.*, chromatophore; *c.v.*, contractile vacuole; *c.w.*, cell wall; *e.s.*, eye-spot; *fl.*, flagellum; *n.*, nucleus; *p.*, pyrenoid.

Quite at the anterior end of the plant are two little vacuoles which contract rhythmically. These are the *contractile vacuoles*. It is difficult to be quite sure of their function, but they probably get rid of waste water used in the process of food-building or carbon assimilation.

The plant swims through the water by means of two threads of protoplasm, the *cilia*, or *flagella*. These protrude from the protoplasm at the anterior end and pass through the cellulose wall. They act as lashes which whip the water. As Chlamydomonas swims forward it also rotates round its long axis.

It is thus seen that while the cell of Chlamydomonas resembles that of Amœba in having protoplasm and a nucleus, it differs from it in many important particulars.

The bounding wall protects the cell of Chlamydomonas and gives it a definite shape.

Movement is no longer effected by general streaming of the protoplasm, but is brought about by special protoplasmic threads, the cilia.

The method of nutrition is widely different in the two cases. Amœba can merely engulf particles of highly organised food ; but Chlamydomonas, by means of its green colouring matter, can build up food from simple inorganic substances.

The free-swimming movement of Chlamydomonas, its eye-spot, and the contractile vacuoles are characters that one would perhaps more naturally associate with an animal than with a plant. One is thus brought to the realisation that there is no sharp line of demarcation in these lowly forms, as there is in the higher types. It is in the different habit of feeding that the animal trend becomes marked off from that of plants. Plants have retained chlorophyll, and with it the power of building up food from the inorganic materials of air and water. Animals, lacking chlorophyll, cannot build up food for themselves from inorganic substances, and are thus ultimately dependent upon green plants for their food.

Reproduction by Fission.

Chlamydomonas reproduces itself in two different ways. A common method is by *fission*. The cell withdraws its cilia and so comes to rest. The protoplasm contracts away from the cell wall. The nucleus divides, and half the protoplasm and half the chromatophore congregate round each new nucleus. A cellulose wall is then formed round each protoplasmic mass, and two cilia protrude through the wall. Thus two new individual *daughter cells* are formed within the wall of the mother cell (Fig. 3). Here they begin to lash with their cilia. Soon the wall of the mother cell is ruptured, and the two daughters swim out. These two new individuals then grow to the size of the mother.

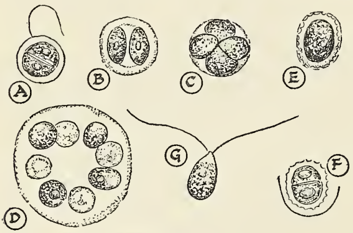


Fig. 3.—*Chlamydomonas Ehrenbergii.* A–D, Stages in asexual reproduction. E, Zygote. F, Zygote dividing. G, Young vegetative individual produced by division of zygote. (After Goroschankin.)

It must be clearly understood here that all the living protoplasm of the "mother" is used up in the formation of the "daughters." There is nothing left of the original parent but the empty cellulose wall.

This method of reproduction is similar to that of Amœba. As, however, there is no cell wall in the latter, nothing at all is left behind when the fission of the cell has taken place.

Very often a second, or even a third, act of fission takes place within the parent, each newly formed daughter cell itself dividing into two. In this way four, or eight, new individuals are formed. These are, naturally, smaller, but soon grow to the size of the original parent.

A second method of reproduction depends upon *conjugation*.

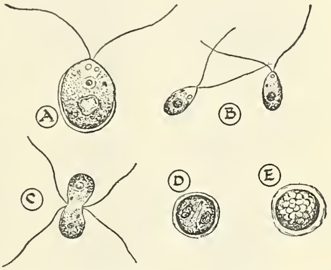


Fig. 4.—*Chlamydomonas* Reinhardi. Sexual reproduction of similar gametes. A, Vegetative individual. B, Gametes. C, Conjugation of gametes. D, Young zygote. E, Ripe zygote. (After Goroschankin.)

Sexual Reproduction by Conjugation.

In this case several divisions take place inside the parent cell, resulting in eight, sixteen, thirty-two or even sixty-four tiny cells within the parent-cell wall (Fig. 4). These daughter cells may, or may not, form cell walls. If they do so they slip out of them when they swim away from the parent cell. Having gained their freedom, they do not continue to grow; instead they join together, or *conjugate*, in pairs. Since two daughter cells fuse to form one individual they are termed *gametes* (Greek, *gameo*, I marry). Two gametes swim towards one another until their anterior ends come into contact and finally join. For a little while they swim about with four projecting cilia. Meanwhile, the protoplasmic contents of the two cells are becoming fused; the nucleus of one cell unites with that of the other, and the protoplasm of the two conjugating cells surrounds the new nucleus thus formed.

The next phase is the withdrawal of the cilia. The cell becomes spherical, and a thick wall is formed round the new individual. This passes through a rest period before entering upon a new cycle of activity. At this stage it is termed a *zygote*.

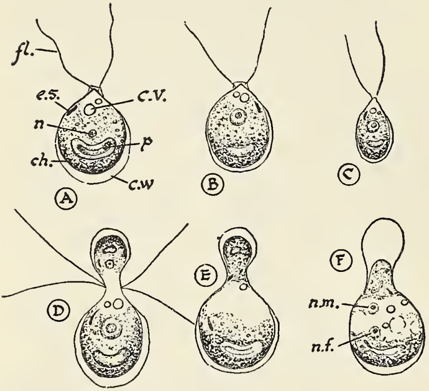


Fig. 5.—*Chlamydomonas monadina*. Sexual reproduction with dissimilar gametes. A, Vegetative individual. B, Macrogamete. C, Microgamete. D, E, F, Stages in conjugation. *ch.*, chromatophore; *c.v.*, contractile vacuole; *c.w.*, cell wall; *e.s.*, eye-spot; *fl.*, flagellum; *n.* nucleus; *n.f.*, nucleus of female gamete, *n.m.*, nucleus of male gamete; *p.*, pyrenoid. (After Goroschankin.)

In reproduction by conjugation is seen the foreshadowing of the sexual process which has become the stereotyped method in all higher plants and animals.

Sexual differentiation is carried a step farther than this in some species of Chlamydomonas. Goroschankin studied the process, and has given some most interesting results of his work. He found that in *Chlamydomonas monadina* some individuals produce a few large gametes, while others form a large number of small ones (Fig. 5). When fusion takes place it always occurs between a large gamete and a small one. The large one is less active, and may even remain motionless in the water; the small one is very active; it swims to the large one, and is absorbed by it. The zygote produced by this fusion then becomes spherical, and a thick wall is secreted within the cell wall of the larger gamete.

There is thus, in this representative of the lowest group of plant forms, a differentiation of sex-character in the gametes. The male is small and active. The female, on the other hand, is large, and contains food for the new individual; it is feebly motile, and may even be entirely stationary.

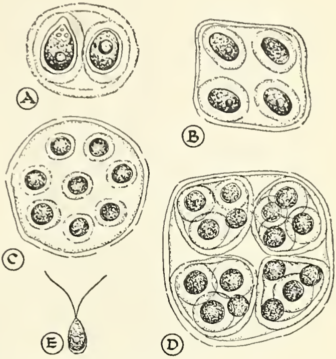


Fig. 6.—*Chlamydomonas monadina.* A–D, Palmella stages. E, Free individual liberated from Palmella condition. (After Goroschankin.)

Palmella Stage.

It sometimes happens in Chlamydomonas that the daughter cells do not produce cilia and swim out from the mother-cell wall. Instead they continue their growth within the wall, which gradually becomes mucilaginous. In time the walls of the daughter cells also become mucilaginous. The divisions may be repeated several times, until a large mucilaginous mass results, containing many cells. This is termed the *Palmella* stage (Fig. 6).

It is not known what are the external conditions which give rise to this non-motile method of living in Chlamydomonas. Sooner or later the cells become motile and escape from the mucilaginous sheath.

PRACTICAL WORK

Living Chlamydomonas should be examined under the microscope, but in their moving state it is almost impossible to draw them.

A drop of iodine under the cover slip brings them to rest by killing them. As a rule, after this treatment the long cilia are clearly seen.

CHAPTER III

PANDORINA, EUDORINA, VOLVOX

It is to the power of protoplasm to adjust itself to changed conditions that all evolutionary development is due.

In Amœba muscular reactions follow sense impressions. Amœba, too, is adaptable ; it responds in such a way to changes in its environment that it can carry out all vital functions under slightly changed conditions.

Had it not been for this power that protoplasm possesses—the power of undergoing certain modifications in response to some influence outside itself—the world to-day would still be peopled only by primitive creatures, closely resembling Chlamydomonas and Amœba.

One of the simplest individuals showing an advance in structure upon Chlamydomonas is Pandorina.

Pandorina.

In Chlamydomonas, as a result of certain changes that have not been formulated, it sometimes happens that daughter cells do not escape from the mother-cell wall. They themselves divide and still remain clustered, thus producing the Palmella stage already described (p. 15).

This is a case of temporary association only.

In Pandorina individual cells, usually sixteen in number, live and move as a permanent colony, or *cœnobium*. The individual cells are practically identical with Chlamydomonas. They are in close contact, forming a flat plate, or disk, which is invested with a gelatinous membrane. From this membrane the sixteen pairs of cilia project and lash Pandorina through the waters of the pond in which it lives (Fig. 7).

Reproduction (Asexual).

The simplest form of reproduction in Pandorina is brought about by four successive divisions in each individual cell, producing first a two-celled stage, then a four-celled stage, followed by an eight-celled and, ultimately, a sixteen-celled stage. This last is a daughter colony in every way representing the original colony of sixteen cells. As this happens in every cell of the colony, sixteen-daughter colonies enter upon a free and independent existence when the parent membrane dissolves in the water.

But, as in Chlamydomonas, so here, there is a sexual act of reproduction. It is interesting to note that here, as in *C. monadina*, a difference in the size of the conjugating cells, or gametes, appears to be the rule. The formation of the gametes also results from division of individual cells of a colony, but the number of times the cell may divide is not constant. The greater the number of divisions, the smaller are the resulting individuals. This accounts for the smaller size of the male gametes. The female gametes, or eggs, are the products of colonial cells that have divided less frequently.

Reproduction (Sexual).

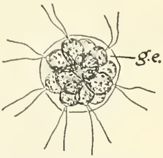


Fig. 7.—A Pandorina colony. *g.e.*, gelatinous envelope.

There is, then, as in *C. monadina*, a difference in the size of the conjugating cells. Also there is here the same advance in evolution of sex, for it seems that very frequently the female gametes are quiescent, and that the small male gametes swim actively, as though seeking their mates.

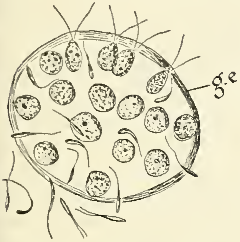


Fig. 8.—(adapted from Gœbel). A female colony of Eudorina, showing spermatozoids (male gametes) piercing the gelatinous envelope (*g.e.*).

Eudorina is another colony of Chlamydomonas-like individuals. It consists of sixteen to thirty-two cells, which at first form a disk. Later the disk changes in shape, becoming basin-like. The rim of the basin narrows, and is finally in contact, so that the flat disk has become a hollow sphere. Here, too, the paired cilia of each cell protrude through an enveloping gelatinous membrane, and the hollow ball is propelled through the water (Fig. 8).

Eudorina.

New asexual colonies arise as in Pandorina. When gametes are formed the several cells of a female colony lose their cilia and become the female gametes, which are never set free. In the male colony the male gametes result from the division of each individual cell into sixty-four, so they are exceedingly small. They are long, narrow, and tapering.

At this point in sex evolution a stage is reached where the gametes differ, not only in size and activity, but in structure also.

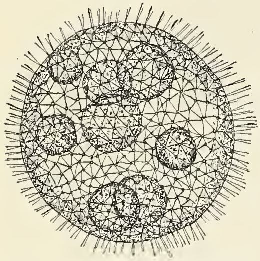


FIG. 9.—Volvox, showing eight daughter colonies in the hollow body of the mother.

Volvox.

In this series of colonial forms Volvox has reached the highest developmental stage. Like Eudorina it is a hollow sphere, but, from the outset, there is definite differentiation in the colony, which consists of many hundreds of cells. Out of all this vast number very few, apparently only eight, have the power of dividing to form daughter colonies. These drop into the hollow body of the mother, where they move actively as long as the surrounding mother colony persists (Fig. 9).

The cells that give rise to the gametes, whether male or female, are, also, always few in number. Like the gametes of Eudorina, they are distinct both in size and form.

Here, then, is a further advance in sexuality. *A definitely limited number of sexual cells occurs*, in relation to a relatively vast number of vegetative cells, marked out, from the first, as sterile.

These colonial forms owe their great interest to the fact that they closely resemble the stages of development that follow the fertilisation of the eggs of higher animals. The fertilisation of an egg is followed by a division of the fused nucleus into 2, 4, 8, 16, then 32. After this, as the number of cells increases, they tend to push away from the centre, and therefore the whole body takes on the form of a hollow sphere.

PRACTICAL WORK

Living Volvox is beautiful and most fascinating. It is well to examine a prepared slide, as well as the living organism. A certain amount of detail can then be drawn.

CHAPTER IV

SPIROGYRA

In Pandorina, Eudorina, and Volvox a number of cells are in permanent contact, living as one individual, either in the form of a flat plate or of a sphere.

Spirogyra is also a multicellular individual. In this case the cells that make up the plant are cylindrical in shape, and, as they are united end to end, a long thread or filament results (Fig. 10, A).

It is the form of the chromatophore, or chloroplast, or colour-bearer, that has given the plant its name. In Chlamydomonas this is a basin-shaped body. In Spirogyra it is a flat ribbon, that winds as a spiral from one end of the cell to the other. All the green colour of the cell is concentrated in this very characteristic ribbon.

There are about twenty-five species of Spirogyra in Britain, all living in the still waters of ponds and ditches. The most striking differences in the various species relate to the number of spiral bands found in each cell, and the closeness or looseness of their spiral turns.

In Chlamydomonas there is one large pyrenoid embedded in the chromatophore. In Spirogyra there are numerous pyrenoids appearing as a row of dots along the ribbon. The fact that the chromatophore is so intensely green at once suggests that it must be the region in which carbohydrates are made. On staining with iodine it is seen that this is so, and that here, too, as in Chlamydomonas, starch grains cluster thickly round each pyrenoid. These are evidently the active centres of the carbohydrate industry.

The community life of Spirogyra is only apparent. Each cell of the filament is just as much an independent individual as is the free-swimming Chlamydomonas. Although it is multicellular morphologically, and although the whole filament is enclosed in a mucilaginous sheath, it has very aptly been described as "physiologically unicellular." Each cell is so aloof from its neighbours in all its activities that it is a matter of no account whether it is one among many, or merely one alone.

If filaments are broken into lengths, each portion grows and regenerates a complete thread, because the growth in length results from the activity of each individual cell, not from that of some special growing region of the filament as a whole.

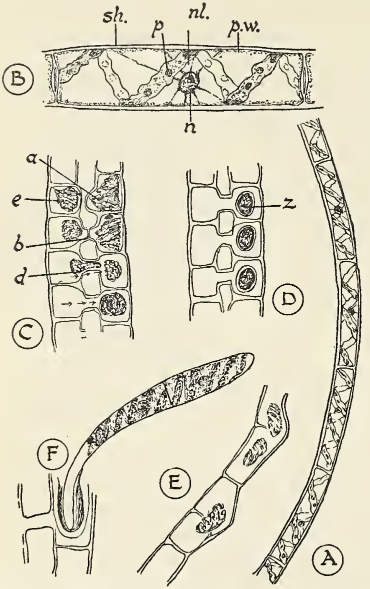


Fig. 10.—Spirogyra. A, A small piece of one filament. B, One cell, highly magnified. C, Two filaments conjugating. D, Filament of zygotes (zygospores). E, Conjugation between neighbouring cells of the same filament. F, Germination of zygospore. *n.*, nucleus; *nl.*, nucleolus; *p.*, pyrenoid; *p.w.*, primordial utricle; *sh.*, sheath; *z.*, zygote.

Growth.

In growth the nucleus of each cell divides into two. A cross-wall of cellulose then divides the original cell, and one daughter nucleus occupies each of the two new cells thus formed. Each cell then grows to the normal size of the units that compose the filament.

In the growth period absorption of water causes extreme turgescence in each new cell. As a result of the internal pressure so produced the whole cellulose wall stretches. The protoplasm of the cell makes this stretched condition permanent by secreting molecules of cellulose from its own substance. These insert themselves between the already existing molecules of the stretched wall, and thus fix it in its stretched condition. But the wall is then too thin for its new length. The further work of the protoplasm, therefore, is to add cellulose to the inner region, thus lining the wall. In this way the wall is made permanently larger and thicker. It bounds a larger cavity. That is, it has *grown.*

What with the stretching of the wall, and what with the activity of the protoplasm in providing new cellulose, it results that the protoplasm itself no longer fills the whole cavity, as it did in the youngest condition of the cell. It is now stretched and is full of gaps, or *vacuoles*, containing cell-sap.

In the fully grown cell the stretching has gone so far that the protoplasm merely lines the cellulose wall, and is known as the *primordial utricle* (Fig. 10, B).

The nucleus occupies a central position in the cylindrical cell. It is supported by extending strands from the primordial utricle. This is most clearly seen in a Spirogyra filament that has one or, at most, two spiral bands. It shows up most clearly, too, after the treatment with iodine. A denser part of the nucleus, the *nucleolus*, also comes very plainly into view.

In spite of their widely different morphological structure, the physiological processes of Chlamydomonas and Spirogyra resemble those of the complex flowering-plant (pp. 304 *et seq*.). In respiration they must, of course, use the oxygen dissolved in the water, while carbon dioxide of the water supplies the carbon necessary for the building up of starch and sugar. Mineral salts are absorbed by osmosis from the water which is the habitat of these very simple plants.

Reproduction.

Reproduction of a very simple kind takes place *vegetatively* when filaments of Spirogyra break up into short lengths, sometimes even into single cells, and each fragment grows into a new filament.

There is also a very pretty method of sexual reproduction ; one, moreover, that is very easily seen. It takes place between two whole filaments of Spirogyra that lie parallel. The walls of the opposing cells of each filament bulge out a little (Fig. 10, C). The bulges increase until finally they meet. At the point of junction the walls disintegrate, so that a hollow canal connects each pair of opposite cells. As this happens all along the line the two filaments now look like a ladder with many rungs.

While these changes have been taking place there has been a rearrangement in the protoplasm and chromatophore of each cell. The spiral has become closer and the primordial utricle has left the cell wall, so that there is a new compactness about the body of the cell.

The preliminaries are now complete. The contents of the cells of one filament pass bodily along each connecting canal into the opposite cells of the second filament. One filament is now no more than a dim outline. The other is a thread of densely filled cells (Fig. 10, D).

This method of *conjugation* is extremely simple. The whole of one cell-body fuses with the whole body of an entirely similar cell. There is just an element of " maleness " in the filament that functions actively, and of " femaleness " in the passive thread.

The whole contents of a cell function as a gamete. After conjugation one whole filament becomes a filament of zygotes. These are rounded off within the cell walls. The outer part of each zygote is modified to form a resistant coat. They are liberated by the breaking up of the filament and probably rest for some little time before they germinate. On germination the resistant outer layer of the zygote breaks. The division of its nucleus leads to the formation of two typical Spirogyra cells (Fig. 10, F). In this way a new filament begins.

There is evidently no preordained sexuality in any one thread, for it happens fairly frequently that adjacent cells of a Spirogyra filament put out protuberances towards each other. The tips of these meet. There is a breaking down of the walls at the point of contact and, using the curved conjugating canal thus formed, the contents of one cell pass over into the neighbouring cell (Fig. 10, E). The two cell-bodies then fuse. From this fusion a zygote results, and this, on germination, gives rise to a new Spirogyra filament in the ordinary way.

Very frequently an examination of Spirogyra reveals a long filament of zygospores in which no suggestion of conjugation can be seen. There are no little protuberances on the cell walls, marking points of attachment with a second conjugating filament. In these cases *parthenospores* or *azygospores* have been formed. The contents of each cell of the filament have become rounded off, and are bounded by a thickened wall. They show, in fact, all the characteristics of zygotes, in spite of the fact that each one has been formed entirely from the contents of one single cell. No act of conjugation has taken place.

NOTE.—The Practical Work is sufficiently indicated in the text.

CHAPTER V

HYDRA

Protozoa are the simplest animals known and consist of one cell only (Greek *protos*, first; *zoon*, animal). All other animals belong to the Metazoa—forms that consist of many cells (Greek *meta*, after, i.e. *later*; *zoon*, animal).

Among the Metazoa the Cœlenterates, or hollow-bodied animals, are the simplest in structure (Greek *koilos*, hollow; *enteron*, gut).

Of Hydra, the simplest Cœlenterate, there are three species living in ponds and ditches.

Habit and Movement.

Hydra is plant-like in habit, for its thread-like body remains almost permanently attached, at one end, to some stem or leaf in the water. It can change its base, however, and its progress then resembles that of the Looper Caterpillar (Fig. 11). The thread curves until its free end, which is provided with tentacles, touches a more distant portion of the plant-member to which it is attached. By means of the tentacles this free, or *distal*, end then grips temporarily. At this period Hydra resembles an eye into which a hook might fit.

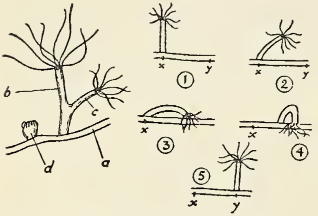


Fig. 11.—Diagrams of Hydra. *a*, plant to which Hydra is attached; *b*, Hydra extended; *c*, branch that will separate and form a new individual; *d*, Hydra contracted. 1–5 show the journey of Hydra from *x* to *y*.

The fixed basal end of the animal then relaxes its hold on the plant and moves in a straight line until it reaches the tentacular end. At this point the base becomes attached once more. The tentacles let go their hold. The thread again extends, spanning out another length. Again the tentacles grip, and the thread again forms a loop. By constant repetition of these activities a forward motion of the animal results.

Much more frequent than this onward motion is the move-

Contraction.

ment of Hydra *in situ*. The thread alternately elongates and shortens. Fully extended, it may be more than half an inch in length, and plainly visible to the naked eye. Upon contraction it becomes a roundish knob, on which the tentacles are reduced to so many minute roughnesses (Fig. 11).

Structure.

Under the ordinary school microscope Hydra is seen to be a hollow body, bounded by cells arranged in two more or less distinct layers (Fig. 12, A). At the fixed end of the animal there is a slight expansion. At the free end there is an open mouth surrounded by a circle of tentacles, generally eight in number. These communicate with the main body and, like it, are also hollow and limited by a two-celled boundary.

As the body of

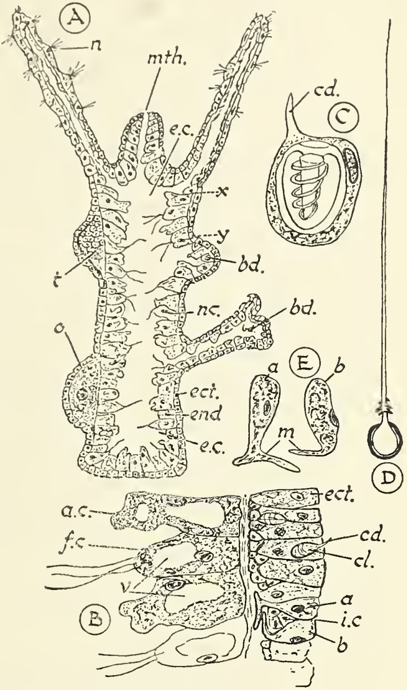


FIG. 12.—Hydra. A, Vertical section. B, The part *x–y* much magnified. C, Undischarged nematocyst. D, Nematocyst discharged. E, The cells *a b* of the ectoderm with muscle-tails. *a.c.*, amœboid cell; *bd.*, Hydra bud; *cl.*, cnidoblast; *cd.*, cnidocil; *ect.*, ectoderm; *end.*, endoderm; *e.c.*, enteric cavity; *f.c.*, flagellate cell; *i.c.*, interstitial cell; *m.*, muscle process; *mth.*, mouth; *n.*, nematocyst; *nc.*, nucleus; *o.*, ovary; *t.*, testis; *v.*, vacuole.

Hydra is cylindrical it is possible to cut it longitudinally through the mouth in a number of planes, so that each half is a mirror image of the other. It is for this reason that Hydra is said to be *radially symmetrical.*

Under the high power of the microscope it is seen that the cells on the outside of Hydra (ectoderm) differ from those of the inner layer (endoderm). It is also evident that the two layers are not quite in contact. Between them there is a thin layer of jelly-like substance, called the *mesoglœa.* This resembles the matrix which determines the shape of Pandorina, Eudorina, and Volvox. In Hydra also it is this layer that gives shape and a certain rigidity to the animal, forming a very simple endoskeleton.

Ectoderm.

The outer layer of Hydra, the *ectoderm*, is, for the most part, made up of cells that are somewhat cone-shaped. Thus, although they are in close contact towards the outside, there are spaces between the ends that are directed inwards.

From the tapering ends of some of these cells filaments are given off which lie lengthwise in the mesoglœa (Fig. 12, E). Under the ordinary school microscope they cannot be seen. They play an important part in the movement of Hydra. Just as the protoplasm of Amœba contracts and expands to bring about a change in its position, so here, in Hydra, the *muscle-tails*, as they are often called, contract and cause the animal to shorten. When they relax the thread regains its normal length.

In all the ectodermal cells of Hydra the nucleus is generally fairly obvious.

Endoderm.

The cells of the *endoderm* are much larger than those of the ectoderm. The ends that abut on the mesoglœa are frequently prolonged into muscle-tails. These muscular processes are much shorter than those of the ectoderm, and lie in the mesoglœa at right angles to the long axis of the body.

The cells of the endoderm are occupied with the animal's feeding processes. The food of Hydra consists of tiny water creatures, such as Daphnia, the Water Flea. These creatures are drawn in through the mouth and swallowed, so that they pass into the hollow part of Hydra, which is, therefore, a gut or intestine, and the forerunner of the alimentary canal.

Some of the endodermal cells secrete a digestive fluid which is poured into the cavity. It acts upon the prey that has been swallowed, partly dissolving it, partly breaking it up into fine particles.

Feeding.

Other cells are able to put out pseudopodia, like those of Amœba, and so actually ingest the fine particles, while the solutions are absorbed (Fig. 12, B).

From other cells, again, whips of protoplasm or flagella stretch out into the hollow cavity, and by their motion cause a movement of its contents, preventing congestion of food in any one part.

All the endodermal cells contain large vacuoles (Fig. 12, B). These are spaces in the protoplasm filled with a clear fluid.

It is obvious that the various functions carried out by the single cell of Amœba are, in Hydra, distributed as the work of special cells. Thus there are distinct muscle-processes responsible for movement. There is a definite mouth for the entry of food. The digestive fluid is only produced by certain cells. Still others are concerned with the absorption of the prepared products.

The division of labour and specialisation of cells is carried even farther than this. Hydra possesses remarkably efficient weapons of defence and attack. It has specialised sexual reproductive organs. According to some observers it even has a primitive nervous system.

In the ectoderm there are gaps between the inner pointed ends of the cells. In these gaps are small cells, which, because they fill up the gaps, are called *interstitial cells*. They give rise to structures of very different character.

Weapons of Defence and Attack.

Many of the interstitial cells, especially at the free end of Hydra and along the tentacles, work their way to the surface and develop into *cnidoblasts* (Fig. 12, B, C). With the ordinary school microscope it is not possible to make out the structure of these organs in their place in the ectoderm. If, however, a drop of 1 per cent. acetic acid is put on the slide with Hydra, then, under the high power of the microscope, long slender threads are seen to shoot out from the ectoderm region. More than this, lying scattered here and there, expelled from the interstitial cells by the force of the animal's reaction, are several minute, balloon-like bodies, whose external form is not difficult to make out.

The Nematocyst.

The balloon-like body, or *nematocyst*, is a capsule which narrows abruptly and is continued as a very long whip-like thread, which is a poisoned dart. Just below the point of the capsule there is a circle of barbs (Fig. 12, D).

Unless a high magnification is available, the arrangement of the nematocysts within the interstitial cells cannot be seen.

The hollow capsule of the nematocyst contains liquid. The pointed end of the capsule is tucked inside this hollow in the fashion of an india-rubber ball, part of which has been forcibly pushed inwards. This tucked-in part terminates in the long, spirally coiled stinging thread, which winds around it.

Projecting from the interstitial cell that contains the nematocyst, that is, from the cnidoblast, or " trigger-cell," there is a stiff, short, protoplasmic process, called the *cnidocil*, or " trigger-hair." When this is touched some change in pressure appears to take place within the bladder, so that its tucked-in part is shot out. The basal end of the thread is first everted and the barbs pierce the prey. The rest of the long thread follows, and, penetrating more deeply into the victim, injects the poison.

In Jelly-fishes, which are closely related to Hydra, the stinging apparatus is identical. Anyone who has been stung by them while bathing knows how extremely painful and paralysing the process is.

The cnidoblasts are doubtless of service in catching food. When a water creature, such as Daphnia or Cyclops, comes in contact with a Hydra tentacle it is probably paralysed and has no chance of escape. By further tentacular action it is drawn into the mouth.

The simplest and commonest method of reproduction in Hydra is one of " budding."

Near the base of the animal there frequently appear swellings (Fig. 12 A). These grow in length, and are seen to repeat, in every detail, the structure of the parent axis from which they grow. When they have reached their full size they are constricted off from the parent. From this time onward they lead independent lives as distinct Hydra individuals.

Reproduction (Vegetative).

There is also a sexual method of reproduction.

Near the base of the tentacles a whole group of interstitial cells is rounded off. Each cell of the group divides, forming two *sperm mother-cells*. Each of these divides again, forming four *sperms*, which are the male gametes. Each sperm, or *spermatozoon*, is a minute oval-shaped portion of protoplasm with a nucleus. A long flagellum extends from the protoplasm and, by means of the flagella, the sperms swim in the water.

Reproduction (Sexual).

Near the base of Hydra a similar group of interstitial cells forms the female reproductive organ, or *ovary*. In this group only one cell undergoes further development. By repeated divisions it gives rise to a number of daughter cells. Of these one only, and that centrally placed, dominates the rest. It behaves very much like an independent Amœba, for, putting out pseudopodia, it absorbs its surrounding sister cells.

This all-devouring cell becomes the egg, which is surrounded by a thin, gelatinous layer. Its increase in size causes a rupture of the ectoderm cells in its neighbourhood, and through the gap thus formed the sperms swim towards it. One penetrates the gelatinous covering and the nucleus of the active sperm fuses with the passive nucleus of the egg.

This fusion marks the beginning of a new Hydra animal, sexually produced. The fertilised egg, as the result of a series of divisions, gives rise to a number of cells. These are in close contact, somewhat in the manner of the cells of Pandorina. This is the *embryo* of Hydra. As development proceeds the cells divide still further. Pressing away from the centre, they form a hollow ball, whose boundary is a single layer of cells. Here there is a certain resemblance to the arrangement characteristic of Eudorina and Volvox.

The interest of this stage, called the *blastocœle* stage, lies in the fact that it is characteristic of so many animals.

At this period the Hydra embryo is still covered with the original gelatinous layer. When it separates from the parent it drops to the mud at the bottom of the pond. As the embryo grows the gelatinous cover gives way and the young Hydra emerges. It is now an elongated hollow body with a wall composed of two layers of cells. At one end an opening forms the mouth, and round this humps appear which form the hollow tentacles.

The study of Amœba makes it clear that protoplasm is irritable, that is, it reacts to impressions from without.

In Hydra, in addition to the irritability common to all the cells of the animal, some of the interstitial cells are said to become modified to form definite nerve cells, closely resembling the nerve cells of higher animals. It is claimed that these are able to receive a stimulus and pass it on. As they are connected with one another in all parts of the body, stimuli may be transmitted from any one point to any other and muscular reaction follows.

Symbiosis.

One species of Hydra is intensely green, and for this reason receives its specific name, *Hydra viridis*. The green colour is due to the presence of unicellular green plants that actually live in the cells of the animal. It seems that both plant and animal receive certain benefits from their "living together," or *symbiosis*. Certainly the plants obtain a sure shelter. Probably, too, it is an advantage to them to have, ready to hand, an unfailing supply of carbon dioxide, resulting from the breathing of the animal. Some of the carbohydrate that the green plants manufacture is, in all probability, absorbed by the animal cells. To this extent Hydra profits by the union.

Below Hydra in the Animal Kingdom are individuals composed of one cell only. Above it are individuals of increasing complexity, made up of tissue-systems and organs. It is this intermediate position of Hydra that gives such great interest to its study. It may be that from such a type as this the more complex animals have evolved.

It is the extreme simplicity of Hydra that makes the possession of organs unnecessary. As its body-wall is made up of two layers of cells only, the water in the Hydra cavity, carrying air and food in solution, is able to reach every single cell of the body. Thus there is no need for circulating blood to carry the oxygen needed in respiration, and the food that is necessary for growth and repair. The same circulation of water that carries air and food can carry off the waste products of assimilation and the carbon dioxide given out by every cell in breathing.

The absence of a blood supply does away with the necessity for a pulsating organ to maintain circulation. There is, therefore, no forerunner of a heart.

Waste material leaves by the mouth through which the food enters. It passes out with an outward flow of water from the cavity. For this reason, therefore, there are in Hydra no organs of excretion, even of a primitive type.

PRACTICAL WORK

Transfer living Hydra, attached to the plant, to a watch-glass, and study its movements both with the naked eye and a hand lens.

Transfer it to a well-slide, and examine it under the low power of the microscope. Mount a specimen on an ordinary slide and, while examining it under the high power, irrigate with 1 per cent. of acetic acid. Put a small piece of blotting-paper at one edge of the cover slip, and by means of a glass rod bring the acetic acid solution to the opposite edge. As the current of weak acid passes across the field the nematocysts are shot out—some with such force that they lie apart from the ectoderm and are very plainly seen.

Prepared slides should also be examined, showing Hydra both in longitudinal and transverse section.

SECTION II

EXTERNAL MORPHOLOGY AND MODE OF LIFE OF SOME MEMBERS OF THE CHIEF CLASSES OF ANIMALS

CHAPTER VI

THE EARTHWORM

"It may be doubted whether there are many other animals that have played so important a part in the history of the world as have these lowly organised creatures." With these words Darwin concludes his book *Vegetable Mould and Earthworms*. Such a summing up at once awakens curiosity and stimulates interest in the common Earthworm.

Earthworms are very widely distributed.

Habitat.

They occur in almost all parts of the world, even in the most desolate islands. Any moist soil will support them, but they soon succumb to drought, and are therefore rare in sandy places. They like a soil that is rich in humus (p. 432) and covered with short, protective vegetation such as grass. A thin layer of fine earth is apparently essential, also deeper layers of soil in which they can burrow in the winter. They are rare in mountainous districts, probably owing to the proximity of the subjacent rocks.

Earthworms are still in a sense semi-aquatic, which suggests their descent from aquatic ancestors. M. Perrier states that one night's exposure to the dry air of a room proved fatal to them, whereas he kept several alive for four months completely submerged in water.

External Structure.

The Earthworm has a long, narrow, roughly cylindrical body, flattened somewhat on the lower side, and tapering at both ends. The backward end is flattened horizontally and somewhat spatulate. Thus a forward and hinder part and an upper and lower surface are marked out. The ends are termed *anterior* and *posterior* and the surfaces *dorsal* and *ventral*.

In Hydra the symmetry is radial (p. 26). The *bilateral symmetry* of the Earthworm marks a great advance, and is the type common to all higher animals.

The worm is slimy to the touch. The skin is smooth and somewhat transparent, so that the blood-vessels can be seen through it. The most conspicuous of these runs from end to end along the dorsal side.

The body is segmented, that is, marked by transverse grooves, throughout its entire length. The number of segments generally varies from 120 to 180.

Situated ventrally at the anterior end is the mouth opening, which is covered on the dorsal side by a little flap termed the *prostomium*. At the posterior end is the *anus*, which is the end of the alimentary tract (Fig. 13).

In addition to the mouth and anal apertures, other openings to the exterior occur. On each segment, except about the first ten anterior ones, there is a tiny dorsal pore. It cannot be seen with the naked eye, but the fluid discharged by the pore can be detected and smelt. This fluid has probably several functions: it preserves the worm from contact with irritating substances; it keeps it damp; it possibly protects it from soil bacteria.

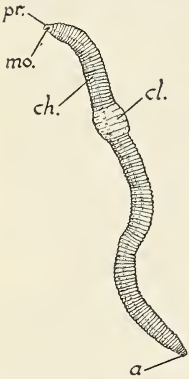


FIG. 13.—Earthworm. *a.*, anus; *ch.*, chætæ; *cl.*, clitellum; *mo.*, mouth; *pr.*, prostomium.

On the ventral side of each segment, except the first three and the last, are two minute pores for the excretion of waste; these are the *nephridiopores*.

There are also four other pairs of apertures. They occur on the ventral surface of certain segments. The pair on segment 15 are surrounded by fleshy lips and are quite conspicuous. The other pairs are less easily seen; they occur on segment 14 and in the grooves between segments 9 and 10, and 10 and 11. All these pores function in connection with the process of reproduction (Fig. 14).

On the ventral flattened surface of each segment there are four pairs of bristles or *chætæ*. These point backwards, and so can easily be felt by stroking a worm from the posterior to the anterior end. They can be seen when it is held up against the light.

In a mature worm there is a swollen ring of mucous-secreting substance, usually about five segments in width, stretching from about the thirty-second to the thirty-seventh segment. These segments are termed the *saddle* or *clitellum* (Fig. 13).

Earthworms move by means of the chætæ, assisted by muscular contractions of the body wall. The muscles in the body wall form two distinct sets. The outer ones are the circular muscles; these are arranged transversely round the body, and therefore the worm becomes thinner and longer as a result of their contraction. The inner set of muscles run longitudinally throughout the entire length of the body, and consequently their contraction causes it to become shorter and thicker (Fig. 15).

Movement.

In order to bring about movement a worm grips the soil with its posterior chætæ, withdraws the anterior chætæ into its body, then raises its anterior end. This forward end is then elongated; the fresh position it takes up is fixed by the chætæ. Next, the posterior chætæ are withdrawn and the hinder portion raised from the soil. Then the forward half contracts while the hinder half lengthens. Finally, the posterior end is contracted and thus drawn up. The chætæ are again fixed in the ground, and the new position established.

When an Earthworm is placed on a smooth surface, such as a piece of glass, the chætæ can get no hold; the worm makes wriggling contortions, but there is no orderly progressive movement.

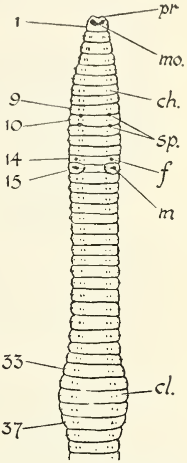


Fig. 14.—Earthworm. Ventral surface of anterior portion. *ch.*, chætæ; *cl.*, clitellum; *f.*, apertures through which female cells are ejected; *m.*, apertures through which male cells are ejected; *mo.*, mouth; *pr.*, prostomium.

Food is derived from the organic remains contained in the soil in which the Earthworm lives. It consists of partially decayed leaves and other forms of humus. When the soil is poor a very large amount is swallowed and worm castings are numerous. If the soil is rich much less is required and worm castings are few.

Feeding.

In Hydra there is but one opening to the exterior. Through this opening or mouth the food is taken into the body cavity, where digestion takes place and waste is finally swept out through the same opening.

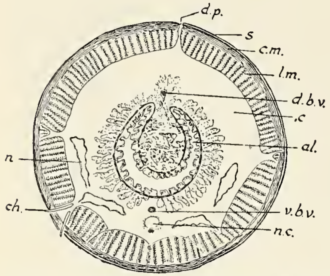


FIG. 15.—Transverse section of an Earthworm. *al.*, alimentary tract; *c.*, cœlom; *ch.*, chæta; *c.m.*, circular muscles; *d.b.v.*, dorsal blood-vessel; *d.p.*, dorsal pore; *l.m.*, longitudinal muscles; *n.*, nephridium; *n.c.*, nerve cord; *s.*, skin; *v.b.v.*, ventral blood-vessel.

A great advance on this structure is seen in the Earthworm. It has a definite food tract, which is distinct from the body cavity, and two apertures, one for the taking in of food and the other for the elimination of waste. The food tract or alimentary canal stretches the whole length of the animal, from mouth to anus. As the food passes along this tract it is gradually digested and absorbed; the waste is expelled at the anus.

The plan of the animal can be represented by two cylinders, one within the other, and united at each end. The outer cylinder represents the body wall, the space between the cylinders is the body cavity or *cœlom*; the inner cylinder stands for the alimentary tract (Fig. 16). The structure of all higher animals may be referred to such a simple type as this.

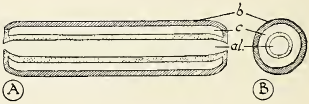


FIG. 16.—Plan of structure of Earthworm. A, Longitudinal. B, Transverse. *al.*, alimentary tract; *b.*, body wall; *c.*, cœlom.

Dissection.

In order to see the alimentary canal a worm is chloroformed. It must then be stretched lengthwise and pinned to a piece of weighted cork. In this position it can be dissected under water in a shallow dish. A photographic developing dish answers the purpose well. The body wall is cut lengthwise along the dorsal side of the first fifty segments. The edges of the cut make good flaps through which it can be still more firmly pinned to the cork.

The dissection shows that the grooving of the exterior corresponds to transverse internal partitions, so that the body is divided into a number of compartments. These are the *somites*, or *metameres*.

The alimentary tract is a straight tube that consists of the following parts: the mouth, or *buccal cavity*, occupies segments 1–2; the *pharynx*, segments 3–6; the *œsophagus*, segments 7–14; the *crop*, segments 15–16; the *gizzard*, segments 17–20. The *intestine* runs throughout the remaining segments (Fig. 17).

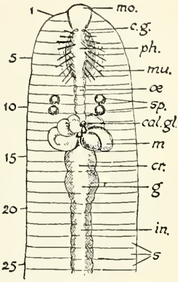


FIG. 17.—Earthworm. Anterior portion dissected from the dorsal side. *cal.gl.*, calciferous glands; *c.g.*, cerebral ganglia; *cr.*, crop; g., gizzard; *in.*, intestine; *m.*, part of male reproductive organs; *mo.*, mouth; *mu.*, muscles of pharynx; *œ.*, œsophagus; *ph.*, pharynx; *s.*, somites; *sp.*, spermothecæ.

Digestion.

The food is drawn into the buccal cavity by the sucking action of the mouth, and at the same time it is moistened by an alkaline secretion which softens and partially digests it. It is then pulled farther into the tube by the action of the powerful oblique muscles of the pharynx. From the pharynx the food is passed along the œsophagus by peristaltic action (p. 154). The œsophagus is a long, thin tube, into which open large calciferous glands, whose secretions neutralise the acids which abound in humus. The glands also serve for the excretion of excess of lime which occurs in a diet of decaying leaves. They probably have other functions also. From the œsophagus the food passes on to the thin-walled crop. It then enters the muscular, thick-walled gizzard. In the gizzard it is ground up and prepared for complete digestion and absorption, which takes place in the intestine. The digested food passes through the walls of the intestine, and is carried throughout the body by a simple system of blood-vessels. Liquid nitrogenous waste and water pass into the body cavity, and leave it through the nephridiopores. Solid waste passes on, and is expelled at the anus.

The blood system of the Earthworm is a simple one. In addition to its function as food carrier it also circulates the oxygen necessary for respiration. Aeration takes place entirely through the skin, and it is for this reason that the skin must be kept damp. The oxygen is carried by a red substance termed *hæmoglobin*. This is dissolved in the blood plasma, and is not contained in special red-blood corpuscles, as it is in higher animals (p. 164).

Circulation and Respiration.

Although the worm has no definite sense organs, it shows certain powers of perception. It is sensitive to touch throughout its entire body ; it is also acutely sensitive to vibrations. A story is told by Darwin of a Peewit which seemed to know that worms would come out if the ground was made to tremble ; accordingly he stood on one leg and beat the turf with the other and thus at once obtained the desired meal.

Senses.

The Earthworm is sensitive to light at the anterior end, although it has no eyes. It can thus distinguish night from day. The possession of this sense can be verified by taking a strong light into the garden at night. Worms, which are already well out of their burrows, immediately retreat.

Their sense of smell can be tested by placing a variety of food just under the surface of the soil in a wormery. They discover and take what they like best. The sense of smell is, however, probably feeble, for they often seem to be entirely unaware of strong-smelling substances placed close to them.

Some sense of taste is manifested in their definite choice of certain foods.

In the sense of hearing they appear entirely deficient.

Interesting experiments have been made by Darwin to test the intelligence of the Earthworm. He studied in great detail the method by which leaves were drawn into burrows, and came to the conclusion that the action was not entirely haphazard, but that in the great majority of cases leaves were pulled in by the narrower end. He concludes thus : " If worms are able to judge, either before drawing or after having drawn an object close to the mouths of their burrows, how best to drag it in, they must acquire some notion of its general shape. This they probably

Intelligence.

acquire by touching it in many places with the anterior extremity of their bodies, which serves as a tactile organ. . . . If worms have the power of acquiring some notion, however rude, of the shape of an object and of their burrows, as seems to be the case, they deserve to be called intelligent, for they then act in nearly the same manner as would a man under similar circumstances."

Nervous System.

Such intelligence as the Earthworm possesses is regulated by a very simple nervous system. This consists of a ventral nerve cord, which divides into two knots of nerve cells, the ganglia, at the head end. These two nerve knots are its brain. Paired lateral nerves pass off from the nerve cord in each segment.

Reproduction.

Worms are hermaphrodite, that is, each one has both male and female sexual organs; self-fertilisation, however, does not take place. Two individuals, while retaining their posterior ends in adjacent burrows, extend their anterior ends, and lie together along about a third of their length, with their ventral surfaces adjacent and their heads pointing in opposite directions.

The male cells or spermatozoa are ejected from the apertures in segment 15. The apertures in segment 14 are those of the ducts, by which the female cells, or ova, are set free. The four apertures which occur between segments 9 and 10, and 10 and 11, open into little chambers, the *spermothecæ*, which act as temporary storing-places for spermatozoa obtained by one individual from another.

What happens exactly when two worms mate is still rather obscure, and different descriptions are given by observers. The simplest account of the process states that, while lying together, each gives up its sperms to the other for storage in the spermothecæ. As soon as the exchange is made the animals separate. A band of substance secreted by the clitellum becomes loose, and the worm begins to wriggle out of it, passing the band along towards its head. As it passes segment 14 some ova drop into it; later it reaches the 10th and 11th segments, and there receives some of the sperms stored in the spermothecæ. Finally, the band-like ring is slipped off at the head end. It immediately hardens in the air, and, owing to its elastic character, closes up at both ends, forming a little cocoon. The cocoon thus contains several eggs and sperms, and fertilisation of the eggs by the sperms takes place within it; only a few of the fertilised eggs, or perhaps only one, develop.

In addition to this method of sexual reproduction, individuals may regenerate themselves when cut into pieces. There is no doubt at all that they can re-form the posterior segments. Often in gardening one comes across some whose original front segments are much larger and darker than the rest. Regeneration of the anterior portion is not a matter of common observation, but has been quoted by many observers.

Habits.

The Worms are nocturnal in habit. Throughout the day they stay in their burrows, which are almost perpendicular and seldom branch. They often remain, especially in the early morning, near the openings of the burrows with their heads just below the surface. In this position they get the early sun, but it is then that "the early bird gets the worm." At night they stretch out the anterior ends of their bodies in search of food while keeping the posterior ends still in the burrow. Apparently healthy individuals seldom leave their burrows entirely, but there is difference of opinion on this point. Many observers have recorded slime tracts, proving that nocturnal journeys are sometimes made. They cannot find their way back to the burrow, and must therefore make new ones if they venture away from the old. It is probable that they leave their burrows in very wet weather. This fact may account for the number of dead worms so often found on the ground after a stormy night. It is sometimes suggested that it is only the sick that are washed out, but if so, one would have to postulate a very unhealthy worm population.

Burrows.

In order to make its burrow an Earthworm pushes away the earth on all sides by using the anterior end of its body as a wedge. If the soil is very loose the burrow may be entirely constructed in this way. When it is difficult to bore through the soil large quantities are swallowed. The burrow is lined with voided earth, which serves to strengthen the sides and also protects the body from scratches. The mouth of the burrow is often plugged with leaves, presumably for warmth. The winter quarters are always lined with little stones. If a wormery is left undisturbed for some months during the winter and then taken to pieces, the worms are found tightly coiled together. Darwin conjectures that the lining of little stones in the winter quarters serves to prevent the closely coiled bodies from coming into contact with the surrounding cold soil, a contact which would hinder adequate respiration.

Action of Earthworms on Soil.

Of quite outstanding interest and importance is the action of the Earthworm in soil formation. As far back as 1777 Gilbert White (*The Natural History of Selborne*) quaintly writes : " Earthworms, though in appearance a small and despicable link in the chain of Nature, yet, if lost, would make a lamentable chasm. For, to say nothing of half the birds, and some quadrupeds which are almost entirely supported by them, worms seem to be the great promoters of vegetation, which would proceed but lamely without them ; by boring, perforating, and loosening the soil, and rendering it pervious to rains and the fibres of plants ; by drawing straws and stalks of leaves and twigs into it ; and, most of all, by throwing up such infinite numbers of lumps of earth called worm-casts, which, being their excrement, is a fine manure for grain and grass. . . . Gardeners and farmers express their detestation of worms, the former because they render their walks unsightly, and make them much work, and the latter because, as they think, worms eat their green corn. But these men would find that the earth without worms would soon become cold, hard-bound, and void of fermentation ; and consequently sterile. . . . A good monography of worms would afford much entertainment and information at the same time, and would open a large and new field in natural history."

Over a hundred years later a " monographer " was found in Charles Darwin, who published his work on *Vegetable Mould and Earthworms* in the year 1881. The actual effect of Earthworms on soil was tested by two different methods.

The first method consisted in calculating the rate at which objects, which have been left at the surface of the soil, get buried by worm castings. Sufficient evidence is given to show that mould to an average thickness of $\frac{1}{5}$ inch is brought up annually by Earthworms. Thus an object left on the surface of the ground sinks an inch in five years. It is in this way that the remains of Roman and other ancient buildings have been preserved.

The second method of computation carried out by Darwin was the actual calculation of the weight of castings brought up by worms over a definite area in a definite time. The amount was found to vary with different kinds of soil, but averaged a yearly yield of fifteen tons per acre.

Darwin concludes his book with this paragraph : " When we behold a wide, turf-covered expanse, we should remember that its smoothness, on which so much of its beauty depends, is mainly due to all the irregularities having been slowly levelled by worms. It is a marvellous reflection that the whole of the superficial mould over any such expanse has passed, and will again pass, every few years through the bodies of worms. The plough is one of the most ancient and most valuable of man's inventions, but long before he existed the land was in fact regularly ploughed, and still continues to be thus ploughed by Earthworms. It may be doubted whether there are many other animals which have played so important a part in the history of the world as have these lowly organised creatures."

PRACTICAL WORK

The external features and movements of living Earthworms should be studied.

The longitudinal and transverse muscles can be seen when a prepared slide is examined with a hand lens.

To see the alimentary tract a dissection must be made as described in the text.

The habits of worms can be observed by constructing a wormery. This can be made in a narrow box with a glass front. Soil of various kinds is added in clearly defined layers and kept damp. Leaves should be put on the top so that the way in which they are drawn into the soil can be observed. Bits of onion, carrot, and other vegetables can also be put on the surface and the selection of food noted.

It is instructive to place worms on the top of pots of damp soil of various kinds, such as a clay soil, a loam, and a sandy soil, in order to observe the relative speed at which they burrow and the amount of castings made during the process.

CHAPTER VII

THE BUTTERFLY

THE Common Cabbage Butterfly (*Pieris brassicæ*) is described partly because it is easy both to obtain and to feed, and also because it is not hidden away at any period of its life-cycle. At the same time, it is well to keep any other insects that are available in order to compare their life-histories with that of a butterfly.

The Egg.

Eggs of the Cabbage Butterfly should be looked for in April and May, or late in July and August—perhaps even as late as September—among the Cabbages and Nasturtiums of the garden.

Fabre (*The Life of the Caterpillar*) states that the caterpillar, while preferring Cabbage, will nevertheless, if Cabbage is not available, eat the leaves of any plant which belongs to the Natural Order Cruciferæ. It will not, however, eat plants of any other Family. He reared the caterpillars equally well on Wall-rocket, Hedge Mustard, Wild Radish, and many other Cruciferous plants.

The eggs are not difficult to find, because the butterfly is very common. Of the two broods the second is much the more plentiful. The eggs are yellow in colour, bluntly conical in shape, and prettily marked with vertical and transverse ridges (Fig. 18). They occur in little groups of from twenty to one hundred. They are so well arranged that there is no waste space and yet no crowding. The groups of eggs are generally fixed to the lower surfaces of leaves, but when the leaf is one that spreads out widely, they may be attached to the upper surface.

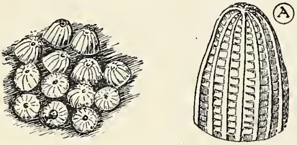


FIG. 18.—Part of a group of eggs of the Cabbage White Butterfly as seen with a hand lens. A, A single egg seen under the microscope.

If possible the laying of the eggs should be watched; the exact time between the deposition of the egg and the emergence of the larva can then be noted. It is a wonderful instinct which leads the butterfly to deposit her eggs on leaves which are suitable food for the young caterpillars.

A leaf bearing a little cluster of eggs should be picked and kept in a pith box. After seven to ten days the young larvæ hatch out. They emerge almost simultaneously. The process should be watched with a lens.

The Larva.

Before the emergence a black dot can be observed at the narrower end of the egg. This is the head. The little animal actually bites its way through by means of a pair of powerful, hard jaws termed the *mandibles*. These jaws work horizontally, not up and down as ours do. Soon the larva has bitten off and eaten a round disc from the top of its egg-case, and has come outside. It goes on eating the egg-case until nothing remains but the glistening circle where it was attached to the leaf.

Emergence.

Fabre gives an interesting explanation of this first meal, which, he states, invariably precedes the vegetable diet. He maintains that the first need of the young larva is to attach itself securely to the smooth, waxy, and sloping surface of the cabbage leaf. For this attachment an immediate supply of silk is necessary. The food required is therefore such as can be quickly assimilated. Now, an animal diet is more nutritious than a vegetable one ; it is easier to digest, and is more quickly absorbed. Further, the egg-case is of a horny nature, and so, too, is silk. One can be transformed into the other with little difficulty. Fabre thus surmises that the caterpillar eats the egg-case first in order to supply the silk glands as quickly as possible.

The tiny larvæ have black shiny heads and yellow bodies with a few white hairs. Almost immediately they start feeding on the leaf. After a few days they cease feeding, and remain motionless for two days. Then the first moult or *ecdysis* occurs. This is a time of some physical strain. A little rest is taken. But very soon the caterpillars begin to eat with even greater vigour than before, and continue feeding until the next moult. Except at the time of moulting, feeding is almost continuous, and the amount eaten is enormous.

Feeding and Growth.

Réaumur has calculated that some of the Cabbage-eating caterpillars eat an amount equal to twice their own weight in twenty-four hours, during which period their weight is increased one-tenth.

After the third moult the caterpillars get more independent; the group is broken, and henceforward each feeds alone. The larva places itself on the edge of a leaf so that the mandibles can work one on each side of the margin.

One moult, or possibly more, occurs before the caterpillar is fully grown.

The method of moulting should be watched carefully. The caterpillar becomes restless, and begins to move its head end from side to side. This causes the old coat, which is now dry, to split. The split occurs along the back over the second, third, and fourth segments, and the clean, fresh coat can be seen below. The caterpillar continues the wriggling movement of the head, and at the same time the front segments swell out, thus making a wedge which lengthens the split a little. The swelling moves gradually backwards, and thus the wedge continues its splitting action. The caterpillar now gets its head through the rent, and walks out of its old skin. The discarded skin is perfect down to the finest details of the hairs and claws, so that it looks like the ghost of the caterpillar itself.

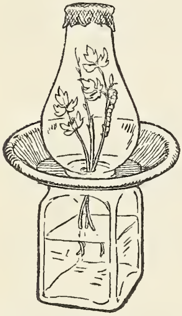


Fig. 19.—Apparatus for rearing caterpillars.

It is probable that at each moult a portion of the internal epithelial tissue, that is, the lining of the alimentary tract and of the respiratory tracheæ, is also cast off.

While the caterpillars are tiny it is well to keep them in a pith box and transfer them to a fresh food leaf each day by means of a small camel-hair paint brush.

As soon as they are large enough they can be kept in a more convenient home. The following apparatus is suitable for rearing caterpillars of all kinds. It is least convenient when Cabbage leaves are used as food, because of the absence of stem and leaf-stalk in this case.

With other Crucifers or with Nasturtium leaves it answers well.

A 2-lb. glass jam-jar is filled with water. Over this is placed an earthenware saucer, in which a small hole has been bored for the insertion of the stem of the food material. A transparent glass gas-globe, the open top of which has been covered with net, is then placed on the saucer and over the leaves (Fig. 19).

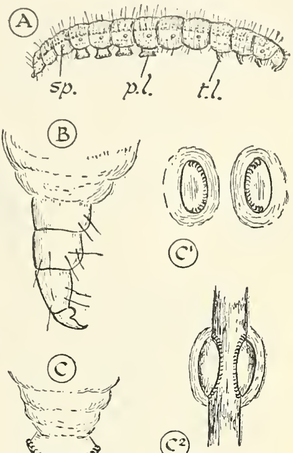


FIG. 20.—A, Caterpillar of Cabbage White Butterfly. B, Leg as seen with a hand lens. C, Pro-leg as seen with a hand lens. C^1, Pair of pro-legs seen from below with "soles" contracted and hooks turning away from each other. C^2, Pair of pro-legs grasping a stem with "soles" expanded and hooks turned towards each other. *p.l.*, pro-leg; *sp.*, spiracle; *t.l.*, true leg.

Within this globe the caterpillars have plenty of air, and their food material keeps fresh and can easily be renewed when necessary. They will not eat withered leaves.

The caterpillars grow until they are about 1½ inches long. At this stage the details of their structure are plain. (Fig. 20, A.)

Structure.

The coat is very different from the one in which the caterpillar emerged from the egg. It is of a pale yellowish-green colour with three yellow lines running throughout its entire length. There are numbers of raised black tubercles on the coat, each of which bears a stiff hair.

The whole body is segmented. Thirteen segments, including the head, can be counted. There are in reality fourteen, but the thirteenth overlaps the fourteenth, which is curled under and not easily seen.

The head is covered with hard cuticle, which enables it to support the hard biting jaws. Six little black spots on either side of the head are minute simple eyes, or *ocelli*. They are placed towards the ventral side of the face, and are directed downwards so that the caterpillar only sees what is immediately beneath it (Fig. 22). Sight is apparently very poor. When a caterpillar is put into a box with leaves of different kinds, it does not look for its right food, but wanders aimlessly about until it happens to come across it. This inability to find food would lead to the death of the caterpillars if they travelled far, but as, normally, they never leave the food plant on which they are hatched, their limited sense-perceptions seem to be sufficient for their needs. What power they have of protecting themselves against enemies is gained by such artifices as protective colour or disagreeable smell.

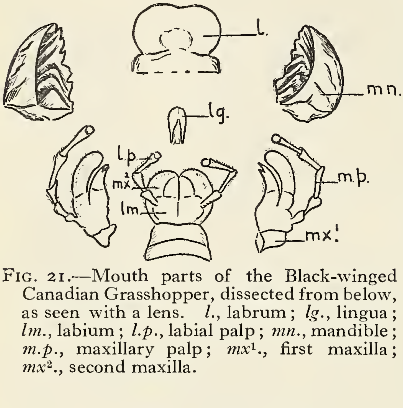


FIG. 21.—Mouth parts of the Black-winged Canadian Grasshopper, dissected from below, as seen with a lens. *l.*, labrum; *lg.*, lingua; *lm.*, labium; *l.p.*, labial palp; *mn.*, mandible; *m.p.*, maxillary palp; *mx*¹., first maxilla; *mx*²., second maxilla.

The long antennæ, which are so characteristic of the Butterfly, are so small at this stage of the life-cycle that they are scarcely seen among the hairs of the head.

In all insects the mouth is complicated, being made up of a number of parts, each of which has some definite function to carry out. Naturally, then, variations occur in the mouth-parts of different insects, these variations depending upon the habits of the insects in question. In all cases, however, they are merely modifications of a fundamental plan, such as is seen, for instance, in the mouth-parts of the Grasshopper (Fig. 21).

General Plan of Mouth-parts.

In the Grasshopper the mouth is overhung by an upper lip, or *labrum*. Beneath this, on either side, are the hard jaws, or *mandibles*; these are unjointed, and are modified for biting and piercing. Beneath the mandibles are the soft jaws, or *first maxillæ*. They are jointed, and terminate in jointed branches, the outer of which is usually the more prominent, and is the *maxillary palp*. These soft jaws serve to hold the food ; they are useless for biting.

Lower again are the *second maxillæ*, whose basal parts are fused together to form the lower lip, or *labium*. These also have branches, and the outer ones are the *labial palps*. The *lingua* or tongue is attached to the upper surface of the labium.

Mouth-parts of the Caterpillar.

In the caterpillar of the Cabbage White Butterfly the strong mandibles are well adapted for the hard biting of a tough-leaved Cabbage. The maxillæ are very small. Projecting downwards from the labium is a little tubular pointed structure, the *spinneret*, from which issues the pale-coloured silk that the caterpillar spins in order to prepare a way for itself, and thus gain firm foothold on its food leaf (Fig. 22).

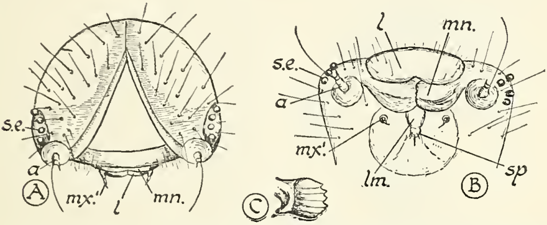


Fig. 22.—Head of caterpillar of the Cabbage White Butterfly as seen with a hand lens. A, From above. B, From the front. C, Single mandible. *a.*, antenna; *l.*, labrum; *lm.*, labium; *mn.*, mandible; mx^1., first maxilla; *s.e.*, simple eye; *sp.*, spinneret.

The Segments.

Behind the head are three thoracic segments, each of which bears a pair of legs. Each leg consists of five joints, and ends in a forwardly curved claw (Fig. 20, B). The fifth and sixth segments of the caterpillar have no appendages. On the seventh, eighth, ninth, and tenth there are pairs of pro-legs, or cushion-feet. These are not true legs. They are not jointed, and are present only at this stage of the insect's existence. They are soft fleshy protuberances, and can be contracted almost out of sight by transverse wrinkling of the elastic skin. They end in soft cushion-like pads flanked by a half-circle of hooked hairs which form adhesive disks (Fig. 20, C).

The eleventh, twelfth, and thirteenth segments bear no appendages. On the fourteenth segment there is a terminal backward-pointing pair of pro-legs, distinguished as claspers.

Respiration.

At the sides of several segments, near the ventral surface, are little black dots. They occur on the second and on the fifth to the twelfth segments, that is, on the first thoracic and first eight abdominal segments (Fig. 20, A). They are the *spiracles*, and are the external apertures of a series of branching air-tubes or *tracheæ*.

In insects the oxygen required for respiration is not carried by the blood. It passes along these branching tubes, which are in communication with the atmosphere by means of the spiracles. The tracheæ branch again and again, so that the ultimate ramifications come into contact with all parts of the body and ensure their adequate aeration. The tracheal tubes are strengthened in order to withstand pressure (Fig. 23). As the blood system does not carry oxygen it is poorly developed.

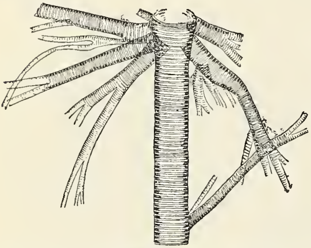


Fig. 23.—Tracheæ of the caterpillar of the Cabbage White Butterfly. As seen under the microscope.

For several weeks while the caterpillar is growing it never leaves its foodstuff. Its one aim is to eat. It apparently eats without ceasing, except for a little while when a moult is taking place. When it has devoured one leaf it moves on to the next.

When, however, full growth is attained, a restlessness occurs, and a desire to leave the foodstuff is observed. The home in which the caterpillars have been kept, up to now, is no longer suitable. For the completion of their life-history the following simple cage should be prepared.

Preparation for Pupation.

On a wooden base—a convenient size is about 12 inches by 18—a four-square wooden frame about 12 inches in height is erected. White butter-muslin is stretched tightly over three of the sides and over the top. This can be fastened with drawing-pins, but no gaps must be left through which the caterpillars can escape. The remaining side of the cage is then covered with black net; through this the interior of the cage is clearly seen (Fig. 24). It is convenient, but not essential, to fix one side of the cage as a hinged door; this does away with the necessity for taking out any of the drawing-pins when the cage is opened. A covering of sheet-zinc on the floor is a great advantage, as it is so easily kept clean. Failing this the floor can be lined with white paper, which must be renewed at intervals.

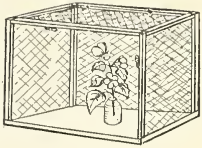


Fig. 24.

As soon as the fully grown caterpillars show a tendency to stop eating they may be removed on their food leaf to the cage. They soon leave the leaf and climb up the sides of the cage. A zig-zag trail of silk marks their ascending path.

From this time onward great demands are made on the silk glands. So great is the desire on the part of the caterpillar to get away from its food, and to climb, that it will travel up the most slippery surfaces apparently without any difficulty. As it travels it moves its head from side to side, spinning all the time, while keeping its abdominal feet fixed firmly to the path already made.

Sometimes the caterpillars stop part-way up the cage, but usually they climb to the top and choose a site underneath, and sheltered by, one of the cross-pieces of wood.

Having finally selected a spot, the caterpillar spins a little mat of silk, into which it fixes its terminal claspers. Keeping this end of its body fixed, and still spinning, it raises and turns its head, and attaches the spun thread to the cage. After this it turns its head in the opposite direction and, carrying the silk round its body at the level of the second or third segment, it attaches it on the other side. By a repetition of these movements the operation is continued until the body is supported by a thick girdle of silk.

The caterpillar now thickens and shortens and, a day or two later, makes its final moult. As the skin splits, it is pushed off backwards through the girdle, remaining attached to the little mat of silk at the posterior end. For a moment the caterpillar's attachment at the posterior end is thus lost, but the new claspers are almost instantly attached to the mat. The creature is now very unlike its former self. Eyes, legs, antennæ, and segments of abdomen are distinct. The wings can be seen and even lifted. But almost instantly the whole is covered over with a chitinous fluid, which is exuded from the body and sets immediately, forming a transparent shell.

The Pupa.

The pupal stage in the butterfly's life-history has now been reached. The pupa in this case is termed a chrysalis (Greek *chrysos*, gold). The chrysalids of many butterflies are golden and iridescent, hence the name. In this case the chrysalis is greenish in colour, with dots of yellow and black.

The change from caterpillar to chrysalis is not so sudden as it appears, for internal changes have been taking place for a long time, and these changes continue while the chrysalis remains apparently quiescent. When a chrysalis is picked up it responds to the contact by a side-to-side movement of its posterior end ; no movement of the anterior end occurs.

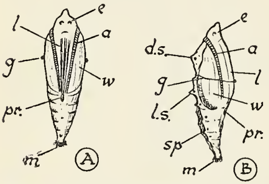


Fig. 25.—Chrysalis of Cabbage White Butterfly. A, Ventral surface. B, From the side. *a.*, antenna ; *d.s.*, dorsal spine ; *e.*, eye ; *g.*, girdle ; *l.*, leg ; *l.s.*, lateral spine ; *m.*, mat ; *pr.*, proboscis ; *sp.*, spiracle ; *w.*, wing.

The coat of the chrysalis bears protective points, which help it to keep firmly attached to its support during this quiescent period. The most marked of these are a prominent spine situated on the dorsal side, and two lateral ones a little way behind it. Between the dorsal spine and the two lateral ones is the girdle, so that the chrysalis cannot possibly fall out. Many of the parts of the future butterfly, the antennæ, the eyes, and the segments of the abdomen, are clearly visible through the transparent case of the chrysalis (Fig. 25).

The pupæ of early summer remain for two or three weeks in this stage. Chrysalids formed from eggs laid in autumn pass the winter in this pupal form. In either case there is a final splitting of the outer coat. The slit occurs dorsally just behind the head, and the butterfly slowly emerges through the hole. The head comes through first, then the legs get free; the wings, limp, damp, and crumpled, follow.

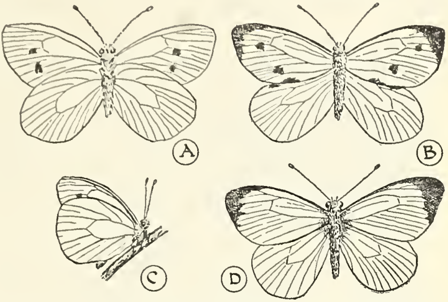


Fig. 26.—Cabbage White Butterfly. A, Ventral surface (both sexes alike). B, Dorsal surface of female butterfly; C, Butterfly in resting position. D, Dorsal surface of male butterfly.

The final stage in the life-history, that of the perfect insect, or *imago*, has been reached. For a while the butterfly stays motionless, then, very gradually, its wings straighten and stiffen, and it takes its first flight.

The Imago.

Now, for the first time, a difference of sex is apparent, for the females have spots on the upper side of the front wings (Fig. 26).

The body is made up of three distinct parts—head, thorax, and abdomen.

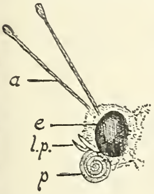


Fig. 27.—Head of Cabbage White Butterfly seen from the side. *a.*, antenna; *e.*, eye; *l.p.*, labial palp; *p.*, proboscis.

The Head.

The head bears two large eyes, a pair of antennæ, and characteristic mouth-parts (Fig. 27). The antennæ are situated above, and to the front of, the eyes. They are long, many-jointed, and club-shaped. They act as sense organs of touch (Fig. 28). Some insect observers state that butterflies and moths wave their antennæ, after a rest-period, before flying off to some particular flower for honey. This suggests that the antennæ function also as sense organs of smell.

The two very large compound eyes are situated on either side, and are immovable, so that the two eyes look in different directions, but their range is so great that the butterfly can see practically all round. It is as difficult to surprise one from behind as from the front. Examination with a lens shows that the surface of the eye, or cornea, is made up of a very large number of polygonal areas or facets, each of which is a minute lens (Fig. 29). Exactly how a butterfly sees is not understood; probably each lens contributes a part of the picture which is made by all the lenses together.

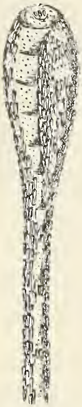


FIG. 28.—End of antenna of Cabbage White Butterfly as seen under the microscope, showing scales and openings to pits in which sensory nerves are situated.

Of the other senses, that of smell is the best developed. Fabre and other naturalists describe experiments in which males have succeeded in finding a captive female which has been shut up in a box, although they have been set free at a great distance from her. They have presumably been guided by the sense of smell.

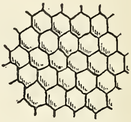


FIG. 29.—Portion of cornea of Cabbage White Butterfly seen under the microscope.

Sensory taste-pits occur in the mouth; but no organs of hearing have been located.

The Mouth.

The mouth-parts are very different from those of the larval stage. The adaptations correspond to the change of diet, which is very striking. The imago requires nothing but highly nutritious, quickly assimilated sugary food.

The stout, biting mandibles have entirely disappeared.

The soft jaws (first maxillæ) have become modified into two long fused tubes, by which nectar is taken from flowers. At the tip are minute papillæ, which are probably organs of taste (Fig. 30, C). These fused maxillary tubes form the *proboscis*. When they are not in use they are coiled like a watch-spring (Figs. 27; 30, A). The complicated structure can be understood by examination of a transverse section (Fig. 30, B). The two tubes are quite distinct and can be separated for cleaning purposes. The sides of the tube facing one another are concave and are locked together by rows of hooks at the edges of the concavity. The proboscis thus comes to consist of three tubes. Nectar is taken up by the central tube only. The outer tubes each contain a trachea for the supply of air, a nerve, and a large number of oblique muscle strands, whose contraction brings about the rolling up of the whole proboscis.

On either side of the mouth are the labial palps (second maxillæ) (Fig. 27). These project forward from the head, and are much longer than in the caterpillar stage. They are sensory in function.

The Thorax.

The thorax is divided into three segments, although the divisions cannot be seen owing to the thick covering of blackish hairs.

A pair of legs is borne on the ventral side of each segment. These are five-jointed. The five joints of the leg, starting from the proximal end, are termed the coxa, trochanter, femur, tibia, and tarsus. The tarsus is again jointed, and ends in a pair of claws and other appendages (Fig. 31).

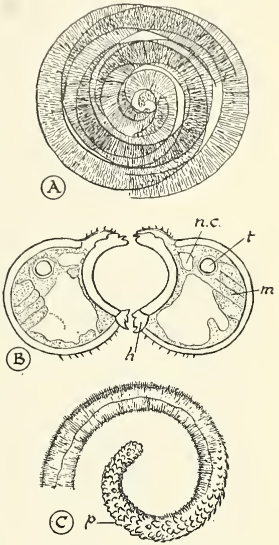


FIG. 30.—Proboscis of Cabbage White Butterfly. A, As seen with a hand lens. B, Transverse section seen under the microscope. C, Tip of one tube under the microscope. *h.*, hook; *m.*, muscle strand; *n.c.*, nerve cavity; *p.*, papilla; *t.*, trachea.

On the dorsal side of the thorax, on the second and third segments, the wings are borne. They are covered with a powdery substance which, under the microscope, is seen to consist of scales of many different shapes. The scales are modified hairs, and some of them are quite hair-like in appearance ; the majority are expanded into various shapes, and are borne on tiny stalks (Fig. 32, B). The scales all lie on the wing in one direction like tiles on a roof (Fig. 32, A).

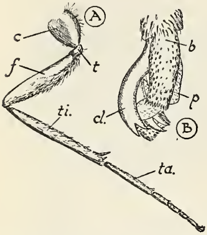


FIG. 31.—A, One of the third pair of legs of the Cabbage White Butterfly with some of the hairs and scales brushed off. Careful dissection is necessary to see the first two joints. B, Last joint of tarsus showing pair of double claws for grasping, a central pad—the pulvillus—which is probably sensory to touch, and two brush-like appendages, one on either side, which are possibly used to clean the claws. *b.*, brush ; *c.*, coxa ; *cl.*, claw ; *f.*, femur ; *p.*, pulvillus ; *t.*, trochanter ; *ti.*, tibia ; *ta.*, tarsus.

The Wings.

The wings are of a creamy white colour, lighter above than below, with black or brownish marks. On the upper surface of the front wing there is a black marking at the apex and a small smudge of black at the base. In the female there is also a small patch of black at the hinder edge or inner margin. These markings do not occur on the under surface. There are also two large black spots, one near the middle and the second close to the inner margin. These appear on both surfaces in the female and on the ventral surface only in the male.

On the back wing the markings are similar in both sexes. There is a dark patch on the front margin which is more conspicuous on the upper than on the lower side (Fig. 26).

In order to examine the tracing of the wing the scales must be brushed off. The delicate membrane is then seen to be traversed by a framework of rays. These are termed veins, or *nervules*. Their function is, in part at any rate, to support the wing.

When the butterfly is at rest its wings are perpendicular, so that the ventral surfaces only are visible (Fig. 26, C).

The Abdomen.

The abdomen is long and covered with hairs, so that the number of segments of which it is composed is not evident. There are probably nine in the female and ten in the male. No appendages are borne on this part. Spiracles occur on the first thoracic segment, and there are six or seven pairs on the abdominal segments.

Mating.

When the butterflies emerge from the chrysalids they should be provided with some honey spread on strips of paper. Fresh flowers with honey glands should also be placed in the cage, as well as fresh cabbage leaves on which the eggs may be deposited. It is, however, extremely difficult to get them to breed in captivity. Mating takes place on the wing, and the eggs are fertilised internally.

Egg Laying.

To make sure of procuring eggs it is well to catch some females and put them into the cage. The chances are that some of these will lay eggs on the cabbage-leaves in the cage. The female does not often lay her eggs under observation. She takes infinite care in their deposition, arranging each one with the greatest exactitude by means of her ovipositor; this is a pointed tube borne at the end of the abdomen. A short row of eggs which just touch one another is first laid. In each succeeding row the eggs are placed exactly between those of the previous line, so that no space is wasted, and each egg is somewhat supported by those around it (Fig. 18).

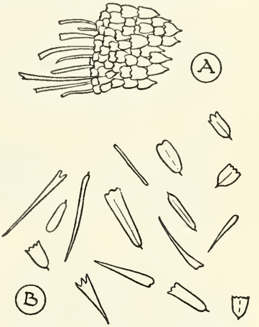


Fig. 32.—A, A small piece of the wing of the Cabbage White Butterfly. B, Scales brushed off wing. As seen under the microscope.

The Ichneumon Fly.

At the time of the metamorphosis from caterpillar to chrysalis there is a high rate of mortality. The caterpillars become limp and unable to complete the change, although they go on working bravely to the very last, spinning mat and girdle. Soon by the side of each dying or dead caterpillar is a little heap of tiny golden cocoons (Fig. 33, B). These are the cocoons of the Ichneumon Fly, the larvæ of which have been feeding on the blood of the caterpillar throughout its life.

Fabre has made a careful study of the relation between

Ichneumon Fly and Cabbage White Butterfly. He says that the eggs of the fly are actually laid within the eggs of the butterfly. He kept the flies with caterpillars of various ages, also with the chrysalids and with the perfect insects; the flies paid no heed to any of them. When, however, the flies were put with the butterfly's eggs, the female flies made a great fuss, showing their satisfaction by brushing their hind legs together. They were then seen to tap the individual eggs with their palpi and, having selected one, each fly darted out a horny prickle from its ventral surface, pricked the egg, and inserted its own egg. Fabre saw several mothers working at the same time, and many visits were paid to the same egg. The number could not be definitely counted; there are generally about twenty cocoons in a little heap by a dead caterpillar, but as many as sixty or seventy have been observed.

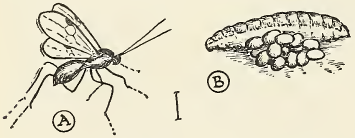


Fig. 33.—A, Ichneumon Fly enlarged. B, Dead caterpillar with group of cocoons of Ichneumon Fly.

The larva of the Ichneumon Fly has no mandibles, and is therefore unable to bite through and damage the internal organs of the caterpillar. Its mouth is simply a little sucking pore. The larva sucks the blood which, in the case of an insect, is diffused in cavities or sinuses, and is not restricted to a system of vessels as it is in the higher animals. Fabre actually reared Ichneumon larvæ on blood taken from Cabbage White caterpillars.

The caterpillar hosts are therefore not killed at once. The life-histories of the two organisms are so exactly balanced that the caterpillar produces enough blood for its own needs and those of its parasite up to the time of the change to the pupa, which takes place simultaneously in the two cases. When it occurs the caterpillar has given up the whole of its blood, and the fly larvæ have reached the stage when they no longer require food.

The latter must, however, get to the exterior, and not be left inside the body of the dying host. To puncture a hole through the caterpillar's skin is not an easy matter for such mouths as the fly larvæ possess; they succeed, however, in making a tiny puncture at the junction between two segments, so tiny that it cannot be seen even after the larvæ have all passed through it. Through this minute hole they crawl quickly in single file and then remain in a little heap just outside. Almost immediately they are transformed into golden cocoons. The flies emerge from their cocoons at the same time as the Cabbage White Butterflies emerge from normal chrysalids, and so the story repeats itself.

The Ichneumon Fly is an insect with four membranous wings (Fig. 33, A). It is black in colour, except for the legs, which are light red.

The story is a sad one for the Cabbage White Butterfly, but the species is so prolific that without some check it might become a very serious nuisance. The Ichneumon Fly helps to keep the balance of nature. Birds, too, play a part in thinning out the large numbers of Cabbage White Butterflies.

Moths.

Butterflies and Moths, while having much in common, possess, at the same time, distinctive characters. Butterflies have usually slender bodies and club-shaped, hairless antennæ. They are generally, but not always, brightly coloured. They fly by day and, when at rest, they keep their wings in a vertical position. Pupation takes place above ground.

Moths, on the other hand, have stout bodies and feathery or pointed antennæ. They are generally less gaily coloured than Butterflies. They fly by night, and keep their wings horizontal when at rest. They generally pupate underground; if not, they cover their chrysalids with a silken cocoon.

Lepidoptera.

Butterflies and Moths belong to the order Lepidoptera (Greek *lepis*, scale, *pteron*, wing). The order is named from the scales which are borne on the wings. In these insects the metamorphosis is always very distinct, and the imago has its mouth-parts modified into a nectar-sucking proboscis.

Another insect which has its mouth-parts modified for the sucking of nectar is the Honey Bee, which is so intimately connected with the pollination of flowers (Fig. 34).

Mouth-parts of the Honey Bee.

In bees the hard jaws or mandibles are present, and are used for cutting wax in the construction of the comb.

The first maxillæ and second maxillæ both take part in the formation of the proboscis. The second maxillæ form the ligula and labial palps.

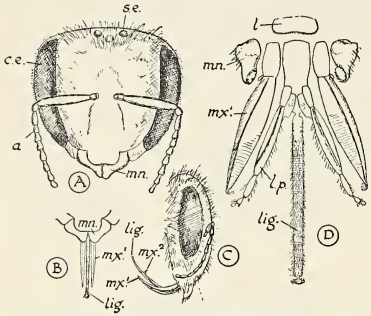


FIG. 34.—Head and mouth-parts of the Honey Bee. A, Head seen from the front with proboscis bent back. B, Same with proboscis extended. C, Head seen from the side. D, Mouth-parts dissected as seen under the microscope. *a.*, antenna; *c.e.*, compound eye; *l.*, labrum; *lig.*, ligula; *l.p.*, labial palp; *mn.*, mandible, *mx*^{1}., first maxilla; *mx*^{2}., second maxilla; *s.e.*, simple eye.

The *ligula* is a long and hairy tongue-like structure, and bears a little spoon-shaped cavity at its tip. The labial palps are long and trough-like, together forming a tube round the ligula. Nectar is taken up by the spoon, and is passed to the hairs on the tongue. It is then sucked up into the mouth by the tube formed of the grooved palps. The first maxillæ form a hard, horny, protective sheath.

When it is not in use the proboscis is bent backwards (Fig. 34, C); as it then lies in a groove beneath the head it is difficult to see.

The nectar is acted on by the digestive juices of the Honey Bee, and in the process the cane sugar of nectar is transformed into the grape sugar of honey and the proportion of water is much decreased (p. 335).

The Lepidoptera is one of the orders of the Class Insecta. This class in some measure takes the same place among the Invertebrates as the Birds take among the Vertebrates. They are the flying Invertebrates. They never achieve a large bulk, which would be an obvious disadvantage to flying creatures, but the class is amongst the most successful of living animals, and the number of species is very great.

General Characters of Insects.

Insects all pass through a very definite life-cycle, in which distinct and apparently abrupt changes, or metamorphoses, take place. The egg hatches into a larva. The larval stage is the period of feeding, and may last for a short time only, or may continue for years. When feeding is complete the larva enters into a quiescent, or pupal, stage. From the pupa emerges, finally, the perfect insect, or imago. This, the final and reproductive stage, is not usually of very long duration.

In the case of the Lepidoptera, the larva and pupa are termed the caterpillar and chrysalis respectively.

All insects take in atmospheric oxygen for breathing purposes by means of surface pores or spiracles. The spiracles are the apertures of a series of branched tubes or tracheæ, which ramify throughout the insect's body, carrying oxygen to every part. The walls of the tracheæ are strengthened by cartilaginous bands. By contraction of the walls of the abdomen air in the tracheæ is forced out through the spiracles, and fresh air then enters to take its place. The muscular contraction of the abdomen thus brings about expiration, and the flying insect is helped onward and not retarded by the respiratory process. This is the case also with birds, whereas in non-flying animals muscular contraction produces inspiration and expiration is the recoil.

An insect's body is divided into three parts : head, thorax, and abdomen. Each of these parts is again segmented, although this is not very obvious in the case of the head. The head bears a pair of compound eyes, and usually some simple ones as well, a pair of antennæ, and a certain number of characteristic mouth-parts.

The thorax is divided into three segments, each one of which bears a pair of jointed legs. The second and third segments bear typically a pair of wings ; there are, however, a good many variations ; some insects have two wings only, and in rare cases there are none at all.

PRACTICAL WORK

Cabbage White Butterflies and other insects should be kept as described in the text, so that the complete life-history can be observed. Careful dated drawings should be made of all stages.

Scales should be removed from the wing with a small brush and examined microscopically. The proboscis, antenna, and leg should be examined with a hand lens or compound microscope.

In order to understand the mouth-parts of an insect it is advisable to make and draw a dissection of the mouth-parts of the Grasshopper, which is comparatively large and easy to dissect.

The mouth-parts of the Honey Bee should either be dissected or drawn from a prepared slide.

CHAPTER VIII

FISH

With the Fish the study of Vertebrate animals begins. In Earthworm and Insect support is given by the strengthening tissue of the body wall, which encloses a soft boneless body. In the Vertebrates the support depends upon an internal bony framework. This framework consists of a central axis, to which two pairs of jointed limbs are attached. The limbs, however, are only foreshadowed in the Fishes and are not jointed. The supporting axis or vertebral column is segmented, a condition that allows free movement. The separate bony portions are the vertebræ (Latin *vertere*, to turn). To this bony framework the muscles of the body are attached.

Excluding certain primitive forms, there are five distinct classes of Vertebrates : Fishes, Amphibians, Reptiles, Birds, and Mammals.

The three lowest classes are said to be " cold-blooded." This means that their blood-temperature varies with external changes of heat and cold. Birds and Mammals, on the other hand, are able, by their own metabolic processes, to maintain, to a great extent, a constant temperature in spite of changes in environment ; they are termed " warm-blooded."

The Fishes are the most primitive of the five classes of Vertebrates. Fossil records show that they have a long past history. They are still a very successful and numerous class, forming the greater part of the population of salt water. Throughout their long history they have kept to the water, and have thus been free from competition with the other great Vertebrate groups. The migration of Amphibians and Reptiles from the water to the land has resulted in their being almost obliterated by the Mammals and Birds which have conquered the land and the air. Fish still remain " masters of the sea."

A large number of fish swim freely ; these are termed *free-swimming*. Others keep to the floor beneath the water ; these are the *bottom fish*. A third class bore in the mud beneath the water ; these are the *boring fish*.

A Free-swimming Fish. Surface and Shape.

A free-swimming fish has to move swiftly in a very heavy medium; it is therefore essential that its form and surface should be such as to minimise friction, so that movement is impeded as little as possible.

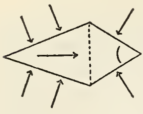


FIG. 35.—Diagram to illustrate shape of fish and pressure of water on its surface.

The fish is shaped like a double wedge; this is best seen when it is viewed from above. The anterior wedge is short and the posterior one long, and thus the widest part is just behind the head. Since the pressure of the water acts at right angles to the surface and is proportional to the area, a reference to the diagram makes it evident that a slight muscular effort is sufficient to drive the fish forward (Fig. 35).

No projecting parts and no neck break the continuity of the outline. Similar modifications in external form occur in other groups of animals that have taken to an aquatic life; they are seen in the Seal (p. 138) and in the Whale (p. 126). The same shape is copied in the man-made torpedo.

The surface of the fish is smooth and very slimy, owing to the presence of mucous glands in the skin. Protection is afforded by an armour of scales, which in no way hamper flexibility. They are beautifully imbricated, and their free ends point backwards, so that they lie perfectly flat (Fig. 36).

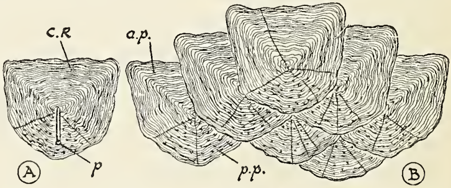


FIG. 36.—Goldfish. A, Single scale passing through lateral line. B, A group of scales showing method of overlapping. *a.p.*, colourless anterior portion covered by other overlapping scales; *c.r.*, concentric rings indicating periods of growth; *p.*, pore of lateral nerve canal; *p.p.*, free posterior portion golden in colour.

Weight and Swim-bladder.

The weight of a fish is approximately the same as that of the water in which it lives. It can therefore rest with its entire weight supported by the water. Some slight adjustment can be made by means of the *swim-*

bladder. This is a thin-walled sac that lies along the ventral side of the backbone and opens, in most cases, into the œsophagus by a short pneumatic duct. In some cases the communication with the œsophagus becomes closed later. The swim-bladder is seen in a dead Herring as a long, silvery, collapsed tube.

Another function of the swim-bladder may be to help in maintaining balance. Some effort is evidently needed to keep the dorsal side uppermost, for in a dead fish the ventral side is uppermost and the head at a lower level than the tail. This position shows that the centre of gravity is just behind the head and nearer the dorsal than the ventral surface.

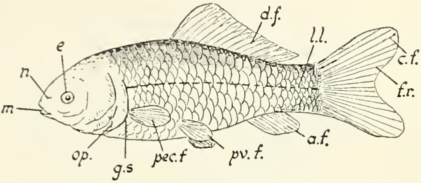


Fig. 37.—Goldfish. *a.f.*, anal fin ; *c.f.*, caudal fin ; *d.f.*, dorsal fin ; *e.*, eye ; *f.r.*, fin ray ; *g.s.*, gill-slit ; *l.l.*, lateral line ; *m.*, mouth ; *n.*, nares ; *op.*, operculum ; *pec.f.*, pectoral fin ; *pv.f.*, pelvic fin.

It is probable, too, that in some cases the swim-bladder helps in respiration by storing excess of oxygen that has entered the blood by the gills.

Muscles.

The muscles are very powerful. The relative proportion of muscle to the rest of the body is large. Since it is muscle tissue that is used as food, there is more to eat in a fish than in any other animal of equal weight. The need for such exceptional muscular force is explained by the watery environment, the great activity of fishes, and the surprising migrations they make. The muscles are segmented. Each mass of muscle, or *myomere*, in both trunk and tail is arranged as a V, with the apex pointing forwards.

Fins and their Function.

The fins are formed from expanded folds of the body-wall, which are supported by cartilaginous rods termed the *fin-rays*. In the median plane there are one or more *dorsal* fins, a tail, or *caudal*, fin, which is typically two-lobed, and an *anal* fin on the ventral side (Fig. 37).

The dorsal and anal fins serve to keep the fish upright in the water with the dorsal side uppermost. The caudal fin acts in conjunction with the body muscles to bring about movement. To effect this, the tail is curved gently to one side, the fin surface being at the same time reduced as much as possible by approximation of the fin-rays. This minimises the resistance of the water. The anterior region of the body is meanwhile slightly curved in the opposite direction to the tail. The tail then makes the swimming stroke : the fin surface is expanded to its full extent, and the tail is rapidly and forcefully straightened against the pressure of the water.

In addition to the median or unpaired fins there are two pairs of paired fins, which foreshadow the limbs of the higher vertebrates. These are the *pectoral*, or breast, fins, and the *pelvic* fins. These, too, are supported by fin-rays (Fig. 37).

The paired fins project like shelves. They are particularly useful for steering, as they act independently on either side. They also help the fish to keep its balance. Sometimes, as in the Stickleback, they are powerful organs of propulsion (p. 74).

Along each side of the body is a distinct line. This is the *lateral*, or *sensory*, line (Fig. 37). It marks the position of a canal, which contains groups of sensory cells, and opens to the exterior by a series of pores (Fig. 36, A). The function of these sensory cells is not fully understood ; probably they detect vibrations in the surrounding water.

Sensory Line.

A Cod's head is good for the examination of the sense and respiratory organs, because it is large and easily obtained.

Sense Organs.

The eyes do not project beyond the general surface of the head. They are covered by a transparent skin ; movable eyelids are absent, therefore fishes cannot close their eyes in sleep.

External nostrils, or *nares*, are present (Fig. 38). There are two openings on each side of the head ; each pair of openings leads into a common cup-like cavity, termed the *nasal sac*. The use of the nares is olfactory, and serves to test the purity of the water. They do not open into the mouth, and therefore have no connection with respiration.

The ears are entirely internal, but the sense of hearing is apparently quite good, as water transmits sound so much more effectively than air.

The mouth is terminal (Fig. 38). There are movable jaws, but no fleshy lips. A large number of small teeth occur on the jaws and on other bones in the roof of the mouth, also at the back of the mouth towards the pharynx and, in some cases, on the tongue (Fig. 39). The function of the teeth is apparently only for the holding of food. The tongue is small and almost immovable.

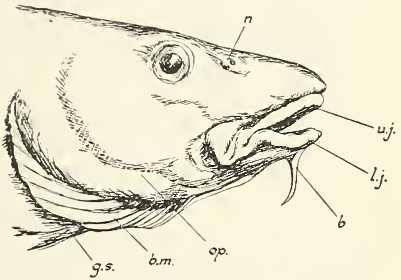


FIG. 38.—Head of Cod. *b.*, barbule; *b.m.*, branchiostegal membrane; *g.s.*, gill-slit; *l.j.*, lower jaw; *n.*, nares; *op.*, operculum; *u.j.*, upper jaw.

Gills and Respiration.

In the Earthworm the oxygen required for respiration is taken in all over the surface through the skin. In the Fish the oxygen is absorbed by the blood of special respiratory organs termed *gills*, which are situated on each side of the back of the mouth at its junction with the pharynx (Fig. 39). Water, with oxygen in solution, is taken in through the mouth and passed over the gills; here some of the oxygen is taken from it. The water is then passed out again through crescentic slits behind the head on either side, towards the ventral surface (Fig. 38). These are the *gill-slits*, which are an essential point of difference between Invertebrates and Vertebrates. Gill-slits are present in all Vertebrates, although in many their use is restricted, while in the higher Vertebrates they persist only in the embryo.

The gill-slits are covered by a stiff flap, the *operculum*, which has a flexible margin called the *branchiostegal* membrane (Fig. 38).

The spaces, at each side of the mouth, that contain the gills are the *gill-chambers*. In each gill-chamber there are four gills. The framework of each gill is a bony *gill-arch*, which bears a double row of triangular, pink *gill-filaments* on its outer edge and bony, tooth-like projections, *gill-rakers*, on the sides and lower part (Fig. 40).

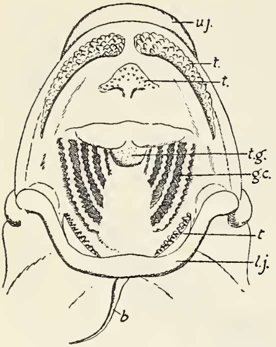


Fig. 39.—Cod. Open mouth showing pharynx and gill chambers. *b.*, barbule; *g.c.*, gill chamber; *l.j.*, lower jaw; *t.*, teeth; *tg.*, tongue; *u.j.*, upper jaw.

The interchange of gases in respiration takes place through the gill-filaments. For this reason they are richly supplied with blood, which is clearly visible through their very thin walls. Because the walls of the filaments are so thin there is the least possible barrier between the blood-vessels and the water. There are two blood-vessels in each filament. In one the blood has lost oxygen and is carrying carbon dioxide, which passes into the water. At the same time oxygen dissolved in the water is absorbed by the blood in the second vessel (Fig. 40, B). The water is taken in by the mouth, and as it is forced outwards through the gill-slits the interchange of gases takes place.

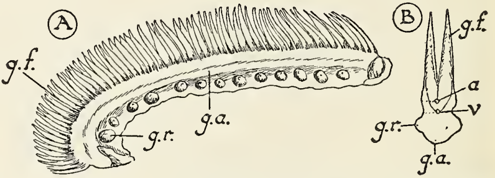


Fig. 40.—Cod. A, Single gill. B, Diagram of transverse section of gill. *a.*, artery; *g.a.*, gill arch; *g.f.*, gill filament; *g.r.*, gill raker; *v.*, vein.

The external movements that accompany respiration can easily be watched. The fish opens its mouth. At the same time the side-walls of the pharynx press outwards on the branchiostegal membranes and thus close the gill-slits.

The whole mouth cavity and gill-chambers are then enlarged by the bulging outwards of the operculum and branchiostegal membrane, which is made possible by the extensible nature of the latter. Water is driven into the mouth by external pressure. Having now obtained a large mouthful of water the fish closes both its mouth and its throat. Pressure of the walls of the pharynx on the branchiostegal membranes is relaxed, and the gill-slits are therefore again opened. Then the operculum moves slowly inwards, thus decreasing the cavity of mouth and gill-chambers, and the water is forced over the gill-filaments and out at the gill-slits, which are the only possible exits.

The familiar phrase "to drink like a fish" is therefore inaccurate, for a fish uses the water in the breathing process, and not for drinking. As a matter of fact, fishes have much less need of water for drinking than have land animals, because they lose none by evaporation.

As in the Earthworm, hæmoglobin is the oxygen carrier, but in fishes, as in the higher animals (p. 164), it is present in red blood corpuscles.

The gill-rakers act as barriers, preventing foodstuff from being lost through the gill-slits.

Unlike the Earthworm, fishes are almost always unisexual, and sometimes the male and female are different externally.

Reproduction.

In most cases the eggs are not fertilised until they are in the water. Sometimes they are fertilised in the body of the female. In other cases, again, the fertilised egg develops within the parent, so that the young are born alive. Generally, enormous numbers of eggs are produced; the "hard roe" of Herring or Cod is a mass of eggs.

Most fishes spend their whole lives either in fresh- or in salt-water. A few, however, migrate at certain periods from the one environment to the other.

Habits of Free-swimming Fishes of Various Types—Salmon.

The habits of the Salmon are particularly interesting. During the winter months adult Salmon travel in large numbers from the sea to the rivers. They are making for the gravelly beds of the higher reaches, where they will deposit their spawn. Even a six-foot waterfall will not stop their progress. They justify the name of "Leaper" (Latin *salire*, to leap) by coiling and springing again and again, until at last they drop into the water above the rocks of the cascade.

The reasons for this "run up" are not clear. The spawning instinct is doubtless one motive, because salt-water is fatal to the vitality of ova. But this cannot be the sole reason, for it begins in some rivers as early as February, and the spawning period lasts invariably from October to January. Other reasons must be involved.

Sir Herbert Maxwell (*British Fresh-water Fishes*) gives interesting suggestions: "Like many of the lower vertebrate animals Salmon manifest intermittent periods of appetite, during which growth proceeds, and of abstinence, during which growth is suspended. . . . Under the stimulus of unlimited nutrition, the fish rapidly increases in bulk, until the time comes when its tissues are so fully stored with fats and proteids that no more nourishment can be assimilated, appetite ceases, and the fish returns to its native river. . . . It appears probable that, the purpose with which the fish visited the sea having been accomplished, it simply returns home, i.e. to its native fresh-water, which is its most congenial environment. After an uncertain period, appetite may return, and the fish obeys the impulse to seek again the salt-water, teeming with various forms of life offering abundance which cannot be found in the river.

"Another agent suggests itself as possibly prompting the return of a fresh-water fish to the river—namely, thirst. Salt-water is not the native atmosphere of salmon; they endure it for awhile without inconvenience, but the time may arrive when they can endure it no longer, and they may then dare every difficulty to reach the refreshing currents of their native stream."

Salmon work their way up-stream in pairs. Often fierce fights occur between two males for possession of a female. Having reached a suitable gravelly bed, the female scoops out a hole by rapid flapping of her tail and lays a few eggs in the little hollow. These are then fertilised by the male, and covered lightly with gravel. The pair then continue their journey farther up-stream, pursuing their occupation daily until all the eggs, which number many thousands, are deposited. In this arduous occupation they lose the beautiful silver mail with which they entered the river from the sea in the spring and gradually change to a dull brown colour. It is most probable that no food is taken by them during their stay in the river; observers state that small fish may swim round them with impunity; on dissection, no food is ever found in the stomach. As a consequence, they are weak, exhausted, and dull in colour when egg-laying is completed.

After about three months the eggs hatch out. For some weeks the young fish remain under shelter, and do not expose themselves to their numerous enemies. During this period they obtain nourishment from a sac of albuminous food material, the yolk-sac, which was provided by the parent, and now appears as a little shoe-shaped body attached to the ventral side of the tiny transparent fish (Fig. 41). When they are about 1 inch in length they leave their hiding-place in search of food, and in due course, as spring passes into summer, they migrate seaward; but enemies are numerous, and a very small proportion ever reach the sea. Nature must therefore be prodigal in numbers, so that the few may survive and the species persist.

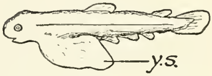


Fig. 41.—Salmon shortly after hatching. Actual length about ¾ inch. *y.s.*, yolk sac.

In order to study the habits of free-swimming fishes, such types as the Goldfish, Minnow, Roach, and Stickleback can be kept. They are little trouble to look after, but it is essential that the aquaria be well aerated and not overcrowded. They can be fed on prepared fish-food sold by all naturalists. This should be given once a day, and not in greater quantity than is required, because it fouls the water. Some very small bits of raw meat, given occasionally, are much appreciated.

Goldfish.

The Goldfish or Golden Carp will live for many years in an aquarium (Fig. 37). Its structure corresponds generally to the description already given. It is a powerful swimmer and very active. The Goldfish is not a British fish; it was introduced from China, but has become acclimatised.

The Minnow is a very suitable fish to keep in a small aquarium (Fig. 42). It is very well known, as it is common in the streams of England and Southern Scotland. Its name is derived from *min*, small. It is long in proportion to its width, and it is almost as broad as deep. Its unceasing activity and changing colour make it particularly attractive. The colour-change has been explained as due to the presence of two dissimilar layers of pigment cells in the skin; the outer layer consists of star-shaped cells with black pigment; the colour varies when these contract and allow light to be reflected from a yellow pigment in the lower layer. The Minnow is a greedy fish, and the sight of a good meal will make it "blush" from grey to yellow.

Minnow.

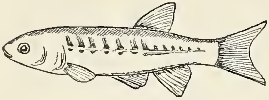


FIG. 42.—Minnow.

As would be expected, the colours are gayest in the male at breeding-time; then the iris is bright golden and the corners of the mouth are red.

Minnows are very sociable. They swim about in little flocks and feed together from a single morsel. The ova, which may number a thousand, are shed in shallow water among the gravel.

The Three-spined Stickleback is the smallest of British fresh-water fishes; it seldom, if ever, exceeds 3 inches in length (Fig. 43). In shape it is much more graceful than the Minnow; both surfaces slope gradually to the slender tail. It is without scales, but certain parts of the body are covered with an armour-plating. On the dorsal side are three sharp, curved spines and a dorsal fin. The fin is very graceful in shape owing to the gradually decreasing length of the fin-rays from the anterior to the posterior edge. A similar shape characterises the anal fin, and in front of this fin also is a short, stout spine.

Stickleback.

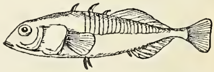


FIG. 43.—Stickleback.

The pectoral fins are large and expanded, and act as the chief organs of propulsion. The pelvic fins, on the other hand, are little more than spines.

With such formidable weapons for offence and defence it would be surprising if the Stickleback were not a great fighter.

Its colours are very variable, and at breeding-time the male is most gaily decked. With shining metallic flanks and silver iris, with bright red throat and breast, he makes up in colour for his diminutive size.

The mating is of a more romantic character than is usual with fishes. The male constructs a nest of water-weeds, which is kept together with mucus from his skin. Into this nest he induces or forces one or more females to enter and deposit eggs. As soon as he has acquired sufficient eggs he closes up the nest, and himself guards it until they are hatched and the young fry able to fend for themselves. Then he pulls the nest to pieces.

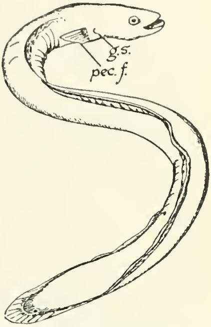


FIG. 44.—Eel. *pec. f.*, pectoral fin ; *g.s.*, gill-slit.

A "Boring" Fish—Eel.

The Eel is a fish of the "boring" type ; it lives in the mud of the river floor ; it glides in and out of crevices and creeps about over land. Its body is almost snake-like, with a tapering head and a tail laterally compressed. The dorsal, caudal, and anal fins are continuous. The pectoral fins are small ; the fish has little need of them either for swimming or balancing ; the pelvic fins are missing altogether (Fig. 44).

The whole body may be regarded as a swimming organ, since progression through the water is brought about by muscular contractions of the whole body, which thus acts as one long tail.

The scales are extremely small and embedded in the skin, and do not therefore hamper movement. Mucous glands are very numerous : the slipperiness of the Eel is proverbial.

The gill openings are small slits at the base of the pectoral fins; they are protected by a fine membrane. The gill cavities are large and the gills are situated at the back of them. When an Eel is taken out of the water the gill cavities often appear as conspicuous swellings on each side of the throat. The gill chamber is still full of water, and so the delicate gill-filaments are afloat, and respiration is going on normally, although the fish is out of water. This explains why Eels are able to take long journeys across-country from one river to another.

Eels are amazingly tenacious of life. They will live in a small aquarium for many years. They stand great extremes of temperature; they can even be frozen hard and still survive.

Life-history.

The Eel, like the Salmon, inhabits both fresh- and salt-water during different periods of its life; but, whereas the Salmon begins its life in fresh-water and comes back to fresh-water to breed, the Eel is born in the sea and returns to it when it reaches maturity.

The life-history of the Eel has been a fascinating mystery for centuries. As late as 1653 Izaak Walton writes that "Eels are bred of a particular dew falling about May or June on the banks of ponds and rivers." Even up to the present time no female with mature eggs has been seen, nor have the newly-laid eggs been discovered. A great deal of the life-story has, however, now been made out.

Every year in May and June young Eels, or "elvers," come to the mouths of our rivers in countless numbers. They swim up-stream, penetrating to every little pool. They live in fresh-water for several years, and, during that time, they eat enormously, grow large, and cause destruction among the river population.

After a certain time, perhaps between the age of seven and ten, some instinct recalls them to the sea. They travel down the rivers and, having reached the sea, swim westwards. The journey is full of peril from Sharks and other large sea fishes. Those Eels that survive at last reach their breeding-ground in the deep waters of the Western Atlantic.

Here, not far from the Bermuda Islands, countless throngs of Eels, both from the Eastern and Western World, meet every year from early spring to late summer. The journey has been long and exhausting, and it is probable that they die after breeding. In their place are countless millions of tiny, transparent, leaf-like creatures (Fig. 45). These were formerly known as *Leptocephali* before their relationship to the Eel was discovered.

These tiny creatures then start on their long journey " home." Those of Western parentage head west for America ; the Europeans travel east. It is a three-years' journey to Europe, and the proportion of survivors is small ; still, it is enough to produce the swarm of "elvers" that reach our shores each year. Nature can afford to be somewhat wasteful, for it has been calculated that the number of eggs in the ovary of an eel 32 inches long is 10,700,000.

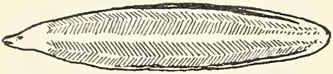


Fig. 45.—Leptocephalus. Enlarged.

During the journey through the Atlantic the little creatures lose the thin leaf-like form, and assume the snake-like contour of the mature Eel. The American Leptocephali have a shorter distance to travel, and they reach their rivers in a year ; they mature more quickly than the European ones.

" Bottom " Fishes.

The " bottom " fishes are those that live on the floor of the water. Modifications have taken place in their general form in connection with their special mode of life. Adaptations for rapid swimming are not needed, because they lie in wait for their food. They need, instead, such modifications as will render them inconspicuous to prey swimming over them.

Their bodies have a flattened form, and the upper side has taken on a protective colouring. Sometimes there are knob-like projections as well, which make the fish almost indistinguishable from the floor on which it rests.

The flattening does not always take place in the same plane. In the Skate or Ray it is dorso-ventral : the upper side is the dorsal side, the ventral side being the one on which the fish rests (Figs. 46 and 47). It is otherwise in the case of the Sole and Plaice ; here the flattening is lateral, and the fish comes to lie on one side, right or left in different species (Fig. 49).

Ray.

The general shape of the Ray is a flat, broad rhomboid (Fig. 46). The pectoral fins are wide and flap-like, and attached to the body almost from head to tail. They act as powerful swimming organs. Swimming is brought about by the undulatory movements of the fins and not by the side-to-side action of tail and body characteristic of other fishes. The tail, which is no longer needed as a swimming organ, has become much reduced in some species ; in others it is developed into a whip lash, provided with a poison spine.

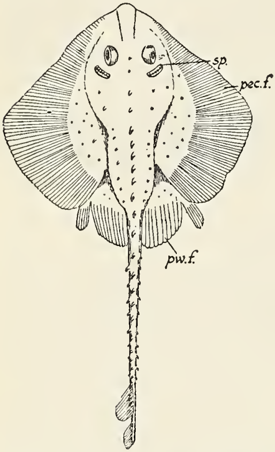


FIG. 46.—Ray. Dorsal surface. *pec.f.*, pectoral fin ; *pw.f.*, pelvic fin ; *sp.*, spiracle.

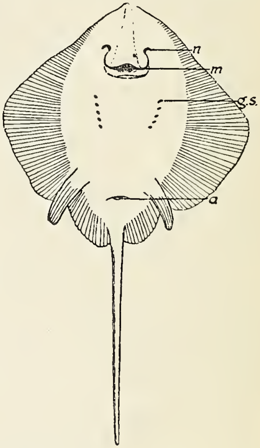


FIG. 47.—Ray. Ventral surface. *a.*, anus ; *g.s.*, gill-slit ; *m.*, mouth ; *n.*, nostril.

The Ray has a pointed snout. Behind the eyes are spiracles ; these are gill-slits communicating with the mouth. The mouth is crescent-shaped and ventral ; on either side of it, and incompletely separated from it, are the nostrils. On the ventral side also are five pairs of gill apertures (Fig. 47). There is no swim-bladder.

The Ray, like its relation the Dog-fish, produces very few eggs, and each one is enclosed separately in a protective case, the familiar "mermaid's purse" (Fig. 48). In the case of the Ray the "purse" is anchored by means of a sticky secretion; that of the Dog-fish has tendril-like filaments which serve to attach it to seaweeds.

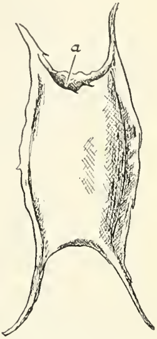


Fig. 48.—Ray. Egg-case or Mermaid's Purse. *a*, aperture through which the baby fish emerged.

Flat-fishes.

Flat-fishes are those in which compression has taken place laterally, as in the Sole and Plaice. The development of these fishes is very interesting. Every little Sole or Plaice is born a symmetrical free-swimming fish which carries its dorsal side uppermost, as does the Goldfish or Minnow. But very soon it changes its habit. Retiring to the bottom, it lives on its side, right or left as the case may be, and spends the rest of its life in this position. The position is maintained when swimming as well as when resting, and very soon the fish loses the power of assuming its original position.

Lateral compression takes place, and the side that is uppermost takes on protective pigments which have the power of varying with changing surroundings.

The dorsal and anal fins become expanded, and stretch from head to tail (Fig. 49). Movement is effected by wave-like motions of body and fins.

Although the actual movement is similar in the Rays and Flat-fishes, the fins modified for the purpose are not the same in the two cases. In the Ray the pectoral fins are expanded for swimming purposes; the dorsal and anal fins perform this function in the Flat-fishes. This is an example of corresponding modifications in structures that are different, but carry on similar functions.

Soles are often quite invisible on their sandy floor until they move; for, in addition to their protective colour, which matches the floor, they are able to use their dorsal and anal fins to throw a little sand over their bodies.

Considerable distortion takes place in the heads of these fishes. As the fish catches the food that swims over it while it is lying on its side, it follows that the mouth becomes distorted. The eye, which would be worse than useless on the under side, travels round or through the head until both eyes lie on the same side, thus giving the fish a very comical appearance (Fig. 49). The position of the paired fins, which are small and of little importance, remains unaltered ; no change occurs either in the position of gill-chambers or gill-slits. As in the case of the Ray, no swim-bladder is present.

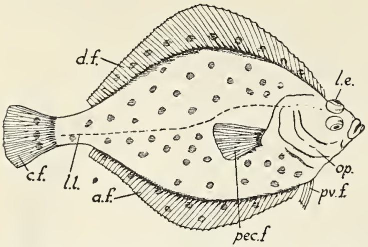


Fig. 49.—Plaice. Right Side. *a.f.*, anal fin ; *c.f.*, caudal fin ; *d.f.*, dorsal fin ; *l.e.*, left eye ; *l.l.*, lateral line ; *op.*, operculum ; *pec.f.*, pectoral fin ; *pv.f.*, pelvic fin.

The study of the development of Flat-fishes throws some light on their evolution. Within limits it is true that every animal during its development climbs up its own genealogical tree. That the Flat-fish is born free-swimming and symmetrical give some clue to its ancestry.

PRACTICAL WORK

To observe the habits of free-swimming fish, Minnows, Sticklebacks, Goldfish, and other small fish can be kept in aquaria as described in the text.

If a sufficiently large aquarium is available, Eels can be kept quite easily.

The habits of Flat-fishes and other large fish should be observed if possible at an aquarium, such as that of the London Zoological Gardens, where they are seen under the best conditions.

The fishmonger's shop will provide other specimens. External structure can be studied from Herring or Haddock, Skate, Plaice or Sole. A Cod's head is particularly good for the examination of the gills.

CHAPTER IX

THE FROG

In studying the development of the Frog the actual transition from life in water to life on land is seen.

Fish live entirely in the water and, by means of their gills, take from it the oxygen necessary for respiration. A frog begins its life as a gill-breather, but, during its development, the gills are gradually replaced by air-breathing lungs, and the frog leaves the home of its ancestors in which life originated. This adventure marks a tremendous advance in the possibilities open to living organisms. They can now spread over the whole land-surface of the globe.

The Frog is a member of the class Amphibia (Greek *amphi*, both ; *bios*, life). The name does not so much signify that the Amphibian can live in both air and water at the same time, but that it is, during its life, first a water-breathing and then a land-breathing animal. Only for a short time is it truly amphibious in the former sense. Were an active, fully developed frog to be kept under water, it would drown almost as readily as any other land animal. Almost, but not quite, because to a certain extent it can breathe through its skin. The Smooth-clawed Frog of South Africa is an exception in that it is entirely aquatic. This species, which belongs to the most primitive group of frogs, can be seen in the Aquarium of the London Zoological Gardens.

Other members of the class Amphibia are the Toad and Newt, and the less familiar Salamander.

Life-history. Breeding.

In early March, or a little later if spring is retarded, there is loud croaking in all the ponds. The frogs are coming down to breed. At times they can be seen in such large numbers that the pond looks solid with their bodies.

The two sexes are very different at this period. The females are of a rich brownish colour, interspersed with bright yellow spots ; they are very bulky, owing to the mass of eggs within their bodies. The males are usually dark olive brown on the dorsal surface and very pale ventrally ; they are slim in build, and have well-developed thickened pads beneath the first digits of their fore-limbs (Fig. 55).

The male rests on the back of the female, clasping her tightly under the armpits by means of his "thumb" pads. In this position they remain together for several days. If a swim is taken, or a leap into the air, or a dart for food, they move together as one. When they are in an aquarium they resist any effort made to separate them.

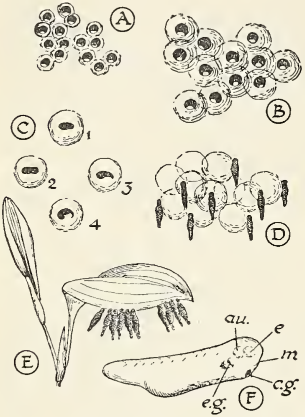


FIG. 50.—Life-history of the frog to the emergence of the tadpole. A, Spawn just deposited. B, Spawn a few hours after being laid. C, 1–4, Stages in development before emergence of tadpole. D, Tadpoles that have just emerged. E, Tadpoles fixed to pond weed by cement gland. F, Tadpole at the time of emergence enlarged. *au.*, rudiment of ear; *c.g.*, cement gland; *e.*, rudiment of eye; *e.g.*, rudiment of external gills; *m.*, mouth-pit.

Spawn.

In due time the female lays her eggs. These are always laid in shallow water, sometimes even in cart-ruts. They are fertilised immediately by the spermatozoa shed over them by the male.

As soon as spawning is accomplished the male releases his hold of the female and takes no further notice of her.

The eggs are spherical but not uniform in structure: the larger part of the egg is black; a small portion is colourless. They are surrounded by an albuminous covering derived from the wall of the oviduct through which they pass in the body of the female. This coating swells greatly when it reaches the water (Fig. 50). Apart from difference in size, a mass of frogs' eggs, or spawn, thus resembles a quantity of hens' eggs without their shells. In the latter case the yolks are the actual eggs, the white of the egg being simply the albuminous covering.

Frogs' eggs are deposited in a long string, but the albuminous coverings merge into a mass when they are in the water. In toad spawn the eggs remain in a long, ribbon-like band of albumen (Fig. 56).

The albuminous covering has several uses : it forms a protection for the delicate eggs and prevents friction ; it prevents overcrowding ; it gives an anchorage to the mass ; it is unpalatable to other inhabitants of the pond ; and it often contains, in the interspaces, green algæ which, by their carbon-assimilation, liberate oxygen, and so help in aeration.

The protoplasm of the egg is mainly confined to the black portion ; the paler part is loaded with food yolk. Consequently the latter is the heavier end, and therefore the egg always floats with the dark side uppermost, thus placing the protoplasm in the most advantageous position for the absorption of heat- and light-energy from the sun.

No change in the egg is observable with the naked eye for about a week. With a lens faint ridges can be seen. The egg is, in fact, segmenting in a manner similar to that which occurs in the cell division of Pandorina, Eudorina, Volvox, and Hydra. The frog is, to a certain extent, climbing up its own genealogical tree. It is following the line of development of the ancestral races that precede it.

After a week or so distinct changes are seen. The egg now appears ovoid. A constriction soon occurs near the middle, producing a somewhat dumb-bell shape ; further elongation takes place, and three regions, head, trunk and tail, are clearly differentiated ; meanwhile, the whole embryo assumes a curved position owing to the limited space in which it is confined (Fig. 50, C).

Hatching occurs about two weeks after fertilisation. The albuminous coating softens, and the little animal, after a preliminary period of wriggling, escapes.

At the time of hatching it has no mouth, and is therefore still dependent on the food supply of the yolk. On the lower side of the head a V-shaped cement gland has developed (Fig. 50, F). The adherence of this gland to some point of the egg-membrane assists in the emergence by presenting a fixed point around which the wriggling movements take place.

A slight pit marks the position of the future mouth; two minute depressions indicate the nostrils; two rounded swellings determine the position of the eyes, behind which the openings to the ear-pits are indicated; two blunt projections occur on either side of the head (Fig, 50, F).

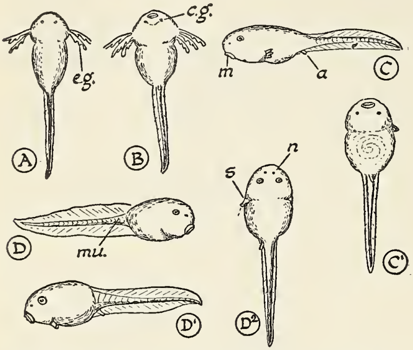


FIG. 51.—Life-history of the frog to the disappearance of the external gills. A, Tadpole from the dorsal side. Two external gills on either side. B, From the ventral side after the development of the third pair of external gills. C, C^1. C from the left side, C^1 from ventral side. Gills on right side already covered by operculum; those on left side almost enclosed. D, D^1, D^2. D from the right, D^1 from the left, D^2 from the dorsal side. External gills have disappeared and operculum has completely fused with the wall except for the "spout." *a*, anus; *c.g.*, cement gland; *e.g.*, external gills; *m.*, mouth; *mu.*, muscles of tail; *n.*, nostril; *s.*, spout.

Tadpole.

On emergence the tiny creature is totally unlike a frog; it more nearly resembles a fish. The name *larva* is given to young animals which are very unlike their parents. In this case the larval form is termed a *tadpole.*

As soon as the tadpole has emerged it fixes itself to some weed by means of the cement gland. All tadpoles from the same brood come out practically simultaneously, and attach themselves in crowded clusters to pieces of pond-weed (Fig. 50, E). For the first few days they hang on to the weed with their heads close together. Those on the outside loosen their hold and try to get a better position by wriggling into the centre of the group. In this struggle others are dislodged. As these in their turn act in the same way, a constant struggle for position is kept up.

During this time the mouth and anus have developed in connection with the alimentary canal. This is straight at first, but, as it is fixed at both ends, it is thrown into coils as it lengthens, the direction of the coil becoming reversed in the middle. It is clearly visible through the transparent ventral wall. The mouth has horny jaws fringed with thick lips studded with papillæ. From now onward the tadpole feeds hungrily, but, for a time, on vegetable matter only.

By this time, also, the two blunt projections on either side of the head have developed into two branching tufts. A third pair develops a little later. It is by means of these thin-walled tufts that oxygen is absorbed during the early days of life. They are the *external gills* (Fig. 51).

While the external gills are functioning temporarily, a respiratory apparatus similar to that of fishes is developing. Four gill-slits, resembling those of the Skate, appear on either side. They communicate with the back of the mouth, and the *internal gills* develop from their edges. The perforation of the gill-slits takes place about the same time as that of the mouth, so that *pharyngeal respiration*, or breathing by internal gills, begins about the same time as feeding. Meanwhile, the external gills have finished their work, and are shrivelling. The cement gland has split into two.

The gill-slits do not remain visible, as in the Skate. A fold of skin, the *operculum*, appears on either side of the head in front of the gill-slits and the shrivelling external gills. The growth of the operculum on the right side is always ahead of that on the left, so that the right gills are covered while those on the left side are still exposed (Fig. 51, C^1). Finally, the free end of the operculum fuses with the body wall below the gills, except for a small aperture on the left side. This aperture is the *spout*, and is now the only means of escape for the water that passes over the gills (Fig. 51, D^2).

The tadpole is now about a month old, and is entirely fish-like in character. No great changes occur for the next fortnight or so. It continues to feed vigorously, and when kept in an aquarium must be supplied with fish-food and pieces of raw meat.

The tail grows longer and more fin-like, and acts as a powerful swimming organ. Through its skin >-shaped markings are clearly seen. They indicate muscle segments similar to the myomeres of a fish (Fig. 52, A).

About seven weeks after hatching the hind legs appear as rounded warts, one on each side of the base of the tail. By the end of a week they are jointed. A fortnight after the first appearance of the limbs the toes are visible. The front legs develop at the same time, but they are at first hidden by the operculum.

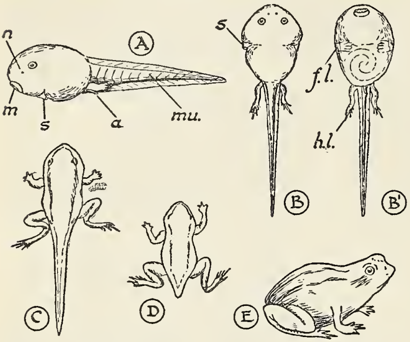


Fig. 52.—Life-history of the frog to the final metamorphosis. A, Tadpole from the left side showing developing hind limb. B, B¹. B from dorsal side, B¹ from ventral side. Hind limbs further developed. Fore limbs seen beneath the operculum. C, Fore limbs free. D, Tail shortening. E, Young frog a little above life-size. *a.*, anus; *f.l.*, fore limb; *h.l.*, hind limb; *m.*, mouth; *mu.*, muscles of tail; *n.*, nostril; *s.*, spout.

When it is about two months old the tadpole's habits change, and it frequently comes to the surface of the water. This is because its lungs are developing, and it needs atmospheric oxygen. At the same time its gills are beginning to degenerate. During its third month of life the visits to the surface are more and more frequent.

When it is about twelve weeks old a distinct, and almost sudden, metamorphosis takes place. Feeding ceases, and a casting off, or ecdysis, of the outer skin takes place. The eyes are now large and prominent. A wide and gaping mouth replaces the round sucking one, with its fringed lips and horny jaws. The front legs break the bonds of the operculum: the left one kicks its way through the spout; the right tears a passage through the operculum itself. The body becomes much thinner owing to shrinkage of the abdomen. The tail is shortening and is being absorbed (Fig. 52, C). The degenerate tissues of the tail thus provide nourishment for the tadpole during this period in which it is not actively feeding. Probably the phagocytes of the blood take an active part in the process (p. 182).

At last the little tailed frog leaves the water and hops on the land. Soon the tail is completely absorbed and the metamorphosis is complete (Fig. 52, E). From this time onward the frog is purely carnivorous.

When it leaves the water its length, including its little stump of tail, is not more than $\frac{3}{4}$ inch. It grows to a length of 3 or 4 inches, and is mature in its third year.

The Adult Frog.

The body consists of head, trunk, and two pairs of jointed limbs of the typical vertebrate type. It has neither neck nor tail. For a swimmer this gradual transition from head to trunk is a useful adaptation. The loss of the tail is somewhat surprising, but there is compensation in the strong swimming character of the hind limbs. A tail would certainly be a handicap to the frog's long leaps on land.

In the sitting position a hump is seen half-way down the back, where the hip girdle articulates with the vertebral column (Fig. 53).

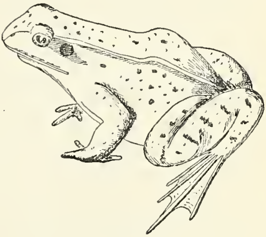


FIG. 53.—Adult frog.

The skin is smooth ; there are neither scales nor hairs. It is kept moist by numerous glands. There is a periodic casting off of the outer epidermis.

The head is broad, triangular, and almost flat. A mouth with a wide gape stretches literally "from ear to ear." The eyes are large and bulging. The upper lid is thick and almost immovable. The lower is immovable and rudimentary. A third, the *nictitating membrane*, is thin and transparent, and moves freely. Behind the eye there is a circular patch of tightly stretched skin, the *tympanic* *membrane* (p. 225). In the Common Frog it is surrounded by a dark elongated patch. The tympanic membranes close over the Eustachian tubes which communicate with the mouth. There is no external ear. On the dorsal side of the snout there are two small nostrils, which also open into the mouth.

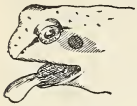


Fig. 54.—Head of frog.

Teeth are present on the roof of the mouth and upper jaw only. Worms and other large animals that cannot be swallowed in one gulp are clasped tightly between the hard lower jaw and the teeth. The frog catches its food by a swift movement of the tongue. The tongue is bilobed and fixed to the anterior end of the floor of the mouth (Fig. 54). When at rest it lies along this floor with its free apex pointing towards the throat. In catching the prey the apex of the tongue is rapidly flicked out of the mouth, carrying some mucous secretion with it. The insect or other small creature sticks to this, and the tongue is then drawn back, carrying the captive to the pharynx. The eyeballs help in swallowing by sinking inwards. In this way they lessen the mouth cavity and send the food backwards.

The fore-limbs consist of three joints—arm, fore-arm, and hand—and terminate in four digits. The first digit, corresponding to the thumb in Man, which is preaxial, i.e. on the side nearest the body, is rudimentary. The third finger (d4) is the longest (Fig. 55, B, C). In a resting position the arm is bent backwards and the forearm and hand forward (Fig. 53). The fore-limbs are short, and are not used at all in swimming.

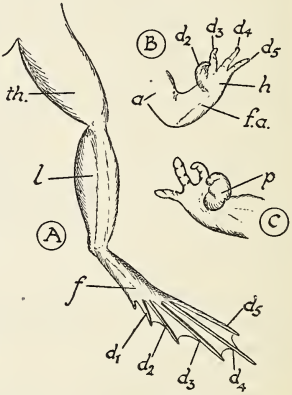


Fig. 55.—Limbs of frog. A, Left hind-limb. B, Left fore-limb. C, Right fore-limb of male at breeding time. *a.*, arm; *d.*, digits; *f.*, foot; *f.a.*, fore-arm; *h.*, hand; *l.*, leg; *p.* pad; *th.*, thigh.

When the frog is swimming rapidly these limbs lie flat against the sides of the body. They are used for alighting after a leap, also for raising the anterior end of the body, both when the animal is at rest and when it is preparing for a leap. They are also useful for slow movements on shore. At the breeding-season a pad develops on the under surface of the first finger (d2) of the male (Fig. 55, C).

The hind-limbs are the chief organs of movement both on land and in water. Like the fore-limbs they are made up of three joints—the thigh, the leg, and the foot—and they terminate in digits. They are, however, very much longer. The thigh and leg are twice as long as the arm and fore-arm, and the ankle and foot are four times the length of wrist and hand. There are five well-developed toes ; the preaxial one, corresponding to the big toe of Man, being the shortest, and the fourth the longest. All the toes are webbed together, thus increasing the efficiency of the limb as a swimming organ (Fig. 55, A). In the squatting position the thigh is bent forward, the leg backward, and the foot forward, so that the knee- and elbow-joints are brought very near together (Fig. 53). Before a leap the three joints of the leg are stretched out into a straight line.

Respiration.

In breathing a frog's mouth is tightly shut. An open mouth would bring about its suffocation. In inspiration air passes through the open nostrils into the mouth cavity, which is enlarged by a depression of its floor. The nostrils are then closed. The floor of the mouth is raised so that the cavity is now lessened, and the air it holds is under pressure. As the œsophagus is closed the only exit for this air is by way of the glottis, and so it is forced down into the lungs.

In expiration, contraction of the ventral surface and flanks causes pressure on the lungs, so that air is forced into the mouth and escapes through the nostrils which are again open.

There are also certain subsidiary methods of respiration.

In addition to the periodic movements connected with pulmonary respiration, there is seen to be a slight rise and fall of the floor of the mouth while the nostrils are kept open.

Air drawn in in this way is at once absorbed by capillaries in the mucous membrane of the mouth.

A third method of respiration is by way of the skin. For this reason, as in the Earthworm, so in the Frog, the skin must always be damp. A frog soon shows signs of acute distress if its skin is allowed to get dry. Its favourite position in a pond is one in which almost the entire body is submerged. Only the nostrils and eyes are above the surface of the water.

During hibernation there is little, if any, pulmonary breathing. Very little energy is being expended, and the cutaneous respiration is sufficient. The frog stays in the mud of pond or ditch, breathing through its skin, and keeping mouth, nostrils, and eyes all tightly closed.

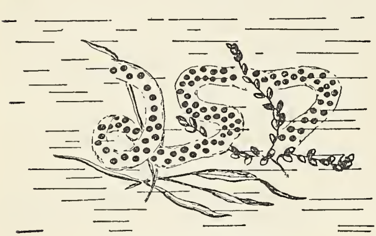


FIG. 56.—Toad spawn.

The need for hibernation is twofold. Some protection from the cold is essential, as the frog, like the fish, is cold-blooded. Further, it would be impossible for it to obtain a sufficient supply of food during this season of the year.

The Toad.

Of the other Amphibians, the toad, both in habits and structure, most nearly resembles the frog. Toad spawn does not form bulky masses, but occurs as a long string of eggs arranged in a row and surrounded by albuminous jelly (Fig. 56). The development of the toad-tadpole is like that of the frog, and the little toad, when metamorphosis is complete, leaves the water, only to return to it at the breeding season. The skin is warty and drier than that of the frog. Teeth are absent. It is of a stumpier build than the frog. The hind legs are not nearly so long and the toes are incompletely webbed, so that its movements both on land and in water are slower and less powerful.

The Newt. Newts spend a large part of their life in water and never lose their long, flattened, fin-like tail (Fig. 57). Their short equal legs are used for progression on land and co-operate with the tail in swimming. They only support the weight of the body when the animal is walking.

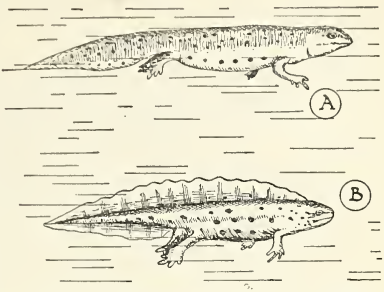


Fig. 57.—Newt. A, Female. B, Male.

Young newts leave the water soon after taking on the adult form. At this stage, when they are in an aquarium, they often leave the water by climbing up the side of the glass. They are mature in their third or fourth year. They then return to the water, spending the spring and summer months in the pond. They constantly push their nostrils above the surface of the water in order to carry out lung breathing.

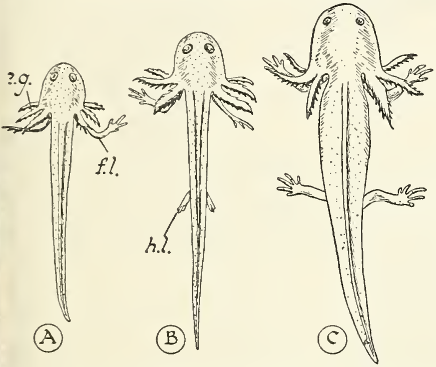


Fig. 58.—Tadpole of Newt, enlarged. A, With fore-limbs only. B, Hind-limbs developing. C, Both fore- and hind-limbs well developed. *e.g.*, external gills ; *f.l.*, fore-limb ; *h.l.*, hind-limb.

A newt moults periodically, stripping off a very thin and transparent, but complete and perfect, skin.

The female lays her eggs singly, placing each carefully on a leaf, which she rolls round it. The tadpoles are slimmer than those of the frog or toad ; their external gills function for a long time ; their fore-legs appear before the hind legs (Fig. 58).

Brief reference must be made to the Salamander because of the interesting discoveries recently made in connection with the larval stage of one species.

The Salamander.

The Axolotl (Fig. 59) has long been known as a Mexican aquatic Amphibian that passed its entire life in the larval stage, in which it was even able to breed. Its connection with any other known Amphibian was not suspected. Some of these animals were brought to Europe and kept under observation. They laid eggs, some of which developed into full-sized Axolotls, while others developed into larvæ which eventually left the water as lung-breathing Salamanders.

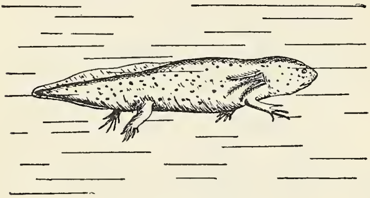


Fig. 59.—Axolotl.

Further researches have established the fact that the metamorphosis of Axolotls can be brought about by feeding them on the extract of either the thyroid or the pituitary gland (pp. 196 ; 198). The failure of the larvæ to develop into Salamanders is due to the fact that in the majority of Axolotls there is a deficiency in the thyroid secretion.

Interesting experiments in this connection have been made also with frogs.

If its thyroid is removed a tadpole stays in the water and grows to a large size, but it never undergoes metamorphosis.

On the other hand, if it is fed on thyroid it will, in a very short space of time, change into a tiny frog the size of a fly.

It is thus established that in Amphibians the normal development of the tadpole into the adult is under the control of the thyroid gland.

PRACTICAL WORK

An aquarium for the reception of frog spawn must be prepared in early March. It is advisable to have a few rooted water weeds if possible. If pond-water cannot be obtained tap-water can be used. A fairly large quantity of the Common Canadian Pondweed (*Elodea Canadensis*) should be put in. This plant will continue to grow quite freely, and is an excellent food for the tadpoles.

Unless the aquarium is a very large one, only a small amount of spawn should be put in. The tadpoles grow much better if not crowded.

After a few weeks some animal food should be given. A supply of Daphnia or other minute water animals is best. Failing these the tadpoles will take fish-food or raw meat. The fish-food can be put into the aquarium as long as only a little is given at a time. If a piece of raw meat is given it is better to move the tadpoles to another vessel for the meal, otherwise the aquarium will be fouled.

When the time for metamorphosis is approaching a fresh home must be prepared.

For the pond an earthenware saucer with sloping sides may be used. This is painted on the outside to render it non-porous. A small quantity of weed and a few small stones are put into the pond ; these will give hiding- and resting-places. The saucer is then surrounded by damp moss or grassy soil. For observation purposes the entire home can be conveniently set up in a large glass tank. The tank must be covered by some perforated material such as wire gauze or butter muslin to prevent the little frogs from hopping out.

It is absurd to leave them at this stage in deep water and expect them to have sufficient intelligence to jump on to a bit of floating cork. They must have shallow water and an easily shelving beach.

Such a home with the addition of larger growing land plants, and a few big stones, is suitable also for adult toads and frogs.

Young frogs are exceedingly difficult to feed. They may take green-fly and other insects, and can often be fed with river-worms if these are dangled in front of them on forceps.

The circulation of the blood can be observed in the tail of a young living tadpole, or the webbing of the feet of a mature frog, if placed under the low power of the microscope.

Newts can be kept in an ordinary aquarium if there are conveniently placed stones above the level of the water. They can be fed on small Earthworms, which they swallow whole.

CHAPTER X

BIRDS

The Amphibian achieved the conquest of the land. The Bird has conquered the air.

Three of the five great groups of Vertebrates, Fishes, Amphibians, and Reptiles are cold-blooded. The power of maintaining an even temperature, irrespective of that surrounding them, is possible only to Birds and Mammals. Both these warm-blooded groups have, without doubt, been evolved from Reptilian ancestors, although along quite divergent lines.

The success of the Bird in its conquest of the air is of such outstanding interest and importance that some account of its historical evolution cannot be omitted.

Evolution of the Bird.

Mammals appear before Birds in geological time. To bring about an achievement so great as that of the Birds, the apprenticeship must have been long and difficult. Many models must have been "tried out" and discarded. Fossil records of some of these failures are available for our study. Other such records trace the line along which success in the air was finally achieved.

Reptiles still in existence include Alligators and Crocodiles, Tortoises and Turtles, Snakes and Lizards.

These are but a poor remnant of a once dominant group that lived on the earth, attempted life in the air, and competed with Sharks for the water.

The huge Dinosaur, whose great length, weak teeth, small brain, vegetable diet, and gregarious habit were all calculated to make life exceedingly difficult in times of drought, did literally become too big to live.

The Pterodactyl, the Flying Reptile, used up both pairs of limbs in an attempt to make wings, and so left nothing to support its body on land. It made a plucky, but unsuccessful, bid for air supremacy.

The Ichthyosaurus, with its great paddle limbs, betook itself to the sea and tried to oust the big fishes.

All these mighty beasts have gone and, for the most part, have left no descendants.

How they became exterminated is unknown. Right up to the end of Mesozoic time they peopled the world and had little competition. Then occurred one of those great breaks of which no records remain. Some mighty and far-reaching change took place in the world. The warm and genial conditions of the Mesozoic period, with its wealth of green food, its warm seas, its soft atmosphere, were no more. These were the conditions under which the Reptiles had flourished. They could not withstand the cold. They had made no provision against food shortage.

When the geological story is again decipherable the Reptiles have become exterminated, or practically so. In their place Birds and Mammals have appeared. Fortunately some links have been found which bridge the great gulf between the Reptiles and the Birds.

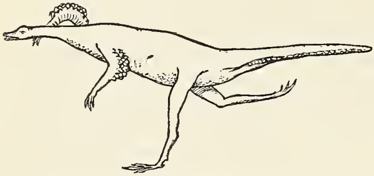


FIG. 60.—An imaginary picture of "Proavis" the forerunner of the birds. (After Nopsca.)

Side by side with the attempt at flying made by the Pterodactyl another experiment was being carried on. The Pterodactyl relied on a membranous wing which stretched from its fingers to its toes, somewhat resembling the wing of a modern Bat (p. 142). In the parallel experiment the fore-limbs only were used up for wings. The hind-limbs were thus left free for support and progression on land.

The particular class of Reptiles from which Birds evolved can only be conjectured. Origin from Dinosaur stock seems most probable. The Dinosaurs were very varied in their habits, and many of them habitually walked on two legs. One can postulate their running and leaping and flapping their fore-limbs in order to give balance and sail. A better and more useful "sail" would result from the broadening of the scales on the outer side of the limb. Such an origin of the wing is suggested by Nopsca (Fig. 60).

In time, perhaps, the reptilian scales became elongated and frayed out at the distal end and so gradually became converted into feathers.

Confirmatory evidence of this bit of evolutionary history is found in the discovery of two specimens of a reptile-like bird from the Jurassic rocks of the Mesozoic age. One of these specimens is in the Berlin Museum ; the other is at the Natural History Museum, South Kensington. The fossil is that of an undoubted bird (Fig. 61). It is bird-like in form and its fore-limbs are modified to form wings. These are covered with feathers. On the other hand, it shows distinct Reptilian affinities. It has a long tail, clawed fingers on the wings, and pointed teeth on its jaws. It is without a beak. In many points of anatomical structure, too, it resembles the reptiles. This fossil has been named Archæopteryx.

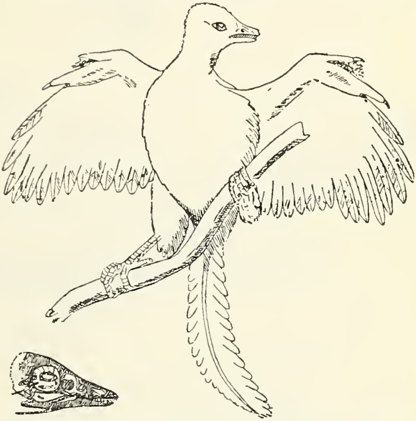


Fig. 61.—Restoration of Archæopteryx. (After Pycraft.) Small figure of skull.

General Structure. In describing the structure of the bird special reference will be made to the Ring Dove. A pair of Doves are very easily kept for observation. A large cage must be provided, and the birds should be given opportunity for wider flying at times. They will then mate and bring up their families and live quite happily. In this way the nesting habits and the rearing of the young can be watched.

The body of the bird is boat-shaped and is perfectly smooth, so that it offers little resistance to the air when flying. It is covered completely with feathers except on the beak, eyes, and feet (Fig. 62).

The two sexes are difficult to distinguish by any external structural differences, but the male bird bows and coos to the female, and so is easily recognised.

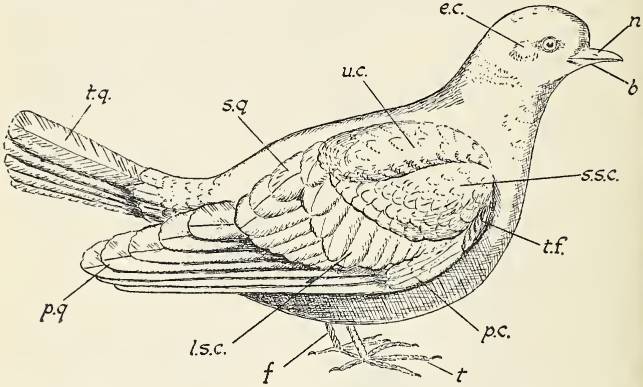


FIG. 62.—General drawing of Dove (diagrammatic). *b.*, beak; *e.c.*, ear coverts; *f.*, foot; *l.s.c*, large secondary coverts; *n.*, nostril; *p.c.* primary coverts; *p.q.*, primary quills; *s.s.c.*, smaller secondary coverts; *s.q.*, secondary quills; *t.*, toe; *t.f.*, thumb feathers; *t.q.*, tail quills; *u.c.*, coverts over upper part of arm.

The front part of the face and jaws is drawn out to form the bony beak which is covered with a horny sheath, the bill.

Beak. In the case of the Albatross and other birds that appear primitive in type, the bill is made up of several separate parts, thus justifying the view that it has been evolved from scales like those that surround a reptile's jaws.

The character of the beak indicates the kind of food taken. The beak of the Dove may be considered a generalised type. It is strong and pointed, with the upper beak slightly longer than the lower, over which it curves. It is more or less triangular in section.

With this type may be contrasted the short, sharp, curved upper beak suitable for tearing food, which is typical of the bird of prey; the long beak of one that gets its food from the mud; the short, stout beak of the insect eater and many others (Fig. 63).

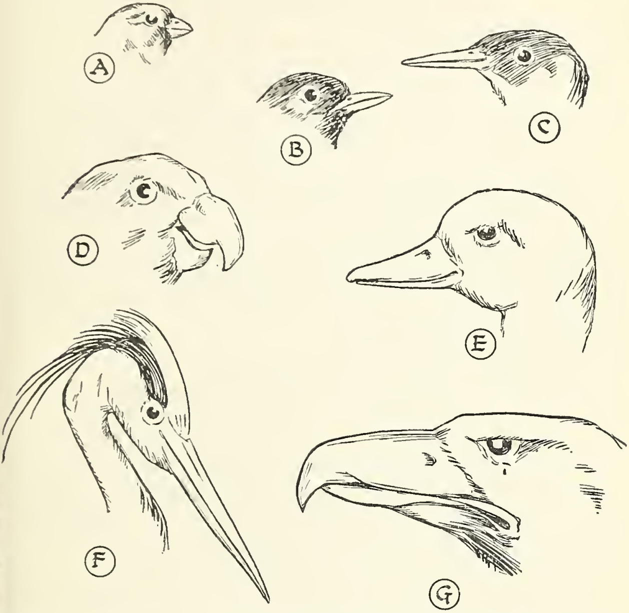


Fig. 63.—Types of beaks. A, Sparrow: short, strong beak of seed-eating bird. B, Blackbird: the not very specialised beak of the bird that feeds on insects, worms, etc. C, Woodpecker: long, strong, straight beak adapted for getting food from trees. D, Parrot: strong hooked beak specially adapted for holding and cracking nuts. E, Duck: broad flat bill which acts as strainer for separating small creatures from the mud. F, Heron: long beak of the wading bird. G, Eagle: strong hooked beak of the bird of prey.

The diet of birds is very varied. Some are vegetarians and eat fruits, seeds, buds, and leaves; or, as in the case of the Woodpecker, the juices of the stem. Others are carnivorous; many feed on fish, others on frogs, the Thrush takes the snail, the Robin the worm, and the vast majority help to keep within bounds the increase in the insect population.

Food.

The jaws never carry teeth in modern birds. In this they differ from Archæopteryx and their reptilian ancestors. For this reason they cannot bite their food and the alimentary canal is modified accordingly. The food passes from the mouth into a thin-walled crop, where it is stored and softened. When it reaches the stomach it is acted on by gastric juices. From the stomach it passes to the gizzard. The gizzard has thick, muscular walls and a horny lining and here the food is ground up by the aid of small stones, which thus help to compensate for the absence of teeth. Some kind of grit must therefore be supplied to caged birds with their food.

Digestion.

The digestion of the bird is very perfect. It eats little that is unprofitable. The amount of excreta or fæces from the alimentary canal is extremely small. The whitish semi-solid pellets, often termed "bird-lime," originate partly from the food canal and partly from the kidneys. It is from the accumulated excreta of birds, which have lived in large numbers undisturbed for countless ages, that the guano deposits have been formed. These deposits are rich in nitrogenous matter and are now worked for the production of agricultural manures.

The nostrils occur as two oblique slits on the upper beak, at some distance from the tip (Fig. 62). The sense of smell appears to be but poorly developed, and a bird does not make much use of it, relying almost entirely on its power of sight.

Sense-organs.

With this deficiency in the power of smell the absence of odour can be associated. Skin glands are almost wanting. There is only one, the *preen-gland*, at the base of the tail. It is often stated that they use the secretion from this gland in preening their feathers, but this is doubtful.

In many birds there is a swollen, featherless patch of skin behind the nostrils, at the base of the beak. Because of its waxy appearance this patch is called the *cere*. It is not very obvious in the Dove, but is pronounced in the Pigeon. It acts as an organ of touch. Apart from the cere there is little localised sense of touch because the body is so completely covered with feathers, scales, or horn.

The eyes are circular and are situated on the sides of the head. They have three well-developed, movable eyelids. In addition to the upper and lower lids, there is a third which is thin, grey, and partially transparent. It passes across the eye from the inner side. This third eyelid is the nictitating membrane which has already been described in the frog (p. 87). It is frequently passed across the eye and serves to keep it clean.

The position of the eyes is such that each eye has its own field of vision. A bird looks at an object with one eye, not with both. A Tit feeding on a coconut is at the same time looking out for possible danger : one eye is alertly observing while the other is turned to the food. It is probable that vision is suppressed in the eye that is not in use at the moment, just in the same way as one makes a " blind " eye of the one not in use when looking down a microscope, although this eye is not actually closed.

Sight is very good. Focal accommodation is amazingly rapid, as is seen by watching any bird. With almost instantaneous rapidity it focuses alternately on possible danger far afield and on a minute particle of food close at hand. Rapid accommodation is necessary not solely because a bird depends chiefly on sight for the detection of its enemies, but also because of the rapidity of its flight.

Behind each eye is a little patch of rough-looking feathers. These are termed the " *ear-coverts* " and cover the ear-tubes (Fig. 62, *e.c.*). There is no external ear. In the young, before the feathers have developed, the ear-tubes are very conspicuous (Fig. 66). The drum of the ear lies at the base of each tube.

The Neck.

The neck is extremely long and flexible. This flexibility compensates for the rigidity of the trunk. When a bird wants to look behind, the neck is turned through an angle of 180°. Indeed, so flexible is the neck that it can touch almost any part of its body with its beak. An extreme case of neck flexibility is seen in the Swan.

The success of birds is largely to be attributed to the development of feathers, a characteristic which is shared with no other animals. The essentials for life in the air are lightness, warmth, and ability to fly. " As light as a feather " is a proverbial expression. By entanglement of air, feathers provide a non-conducting garment for the prevention of loss of heat. The temperature of the Bird is higher than that of any other animals, rising in some cases to 112° Fahrenheit, i.e. 14° higher than that of Man. The wing feathers provide the surface for flight, while the tail feathers serve for steering.

Feathers.

To the character of the feathers the differences in appearance are largely due. So characteristic are they that it is often possible to identify a bird from the examination of a single feather. Some are exceedingly beautiful and decorative. " Fine feathers make fine birds." A plucked bird is a very sorry-looking object.

Feathers are of three types.

The *contour feathers* include the quill feathers of the wing and tail and also the covert feathers which cover the body and are found also at the bases of wings and tail.

Contour Feathers.

A mature quill feather consists of a central axis and wing-like expanded portion. The central axis is made up of a more or less hollow, cylindrical, basal part, the *quill* or *calamus*, and an upper portion, the *shaft* or *rachis*, which is solid, somewhat square in section, convex on the upper surface, and furrowed on the lower one. On either side of the rachis is the expanded feathery part, or *vane* (Fig. 64, A). The vane looks like one continuous sheet, but a slight pull is sufficient to make an oblique rent in it. If, after making such a rent, the vane is pressed gently upwards and outwards between the finger and thumb, the injury can be " mended " so that it is impossible to see where the rent occurred. The vane is made up of separate parts termed the *barbs*. These are borne on the rachis like teeth on a comb, except that they are oblique and are on both sides. On either side of each barb there are branches, or *barbules*. The barbules on the distal side of each barb bear little hooks termed *barbicels* which hook into flanges on the proximal barbules of the next barb

(Fig. 64, B and C). The exact details regarding the barbules and barbicels must be studied in a particular type, but the principle is the same in every case.

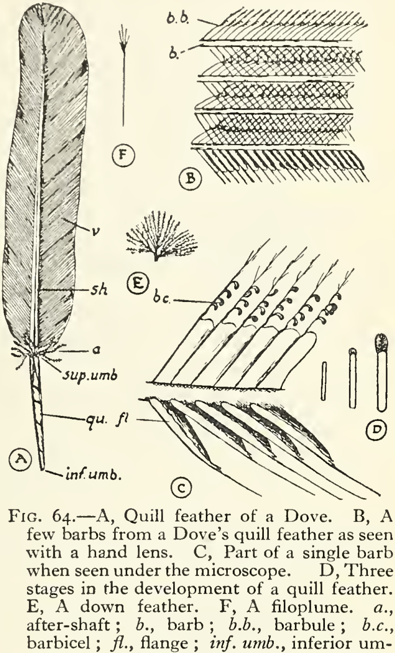


Fig. 64.—A, Quill feather of a Dove. B, A few barbs from a Dove's quill feather as seen with a hand lens. C, Part of a single barb when seen under the microscope. D, Three stages in the development of a quill feather. E, A down feather. F, A filoplume. *a.*, after-shaft; *b.*, barb; *b.b.*, barbule; *b.c.*, barbicel; *fl.*, flange; *inf. umb.*, inferior umbilicus; *qu.*, quill or calamus; *sh.*, shaft or rachis; *sup. umb.*, superior umbilicus; *v.*, vane.

Near the base of the vane a few of the barbs are often fluffy and do not cohere; these are without barbicels. A further fluffy tuft of feathers stands out at right angles from the lower side of the vane at its base. This is termed the *after-shaft.* Its barbs are also without barbicels and cannot therefore form a vane useful for flying purposes. The after-shaft is most strongly developed in such birds as the Emu and the Ostrich. Ostrich feathers of this type have been very popular in the past for the adornment of dress.

At the base of the quill is a tiny hole, the *inferior umbilicus.* It shows where the pulp entered the developing feather (p. 105). A tiny pit at the junction of calamus and rachis is termed the *superior umbilicus.* The little cone-shaped partitions in the otherwise transparent quill indicate the retreating pulp.

The quill feathers of the wing are termed the *remiges.* In these the whole feather is curved, being convex on the upper surface and concave on the lower ; the vane is unequal on the two sides. On one side it is narrow and stiff, and thus makes a good cutting edge. The other side is wider and more flexible.

On the other hand, the quill feathers of the tail, the *rectrices*, tend to be bi-symmetrical and flat.

Other contour feathers are the *coverts* which cover the body. In structure they show the same general features as the quills, but they are softer and have a more pliable rachis.

Down Feathers.

Down feathers occur between the covert feathers but are not present in all birds. In the breast of a Goose or Eider Duck they are seen to perfection. These feathers have a short, soft shaft and feathery barbs which do not interlock (Fig. 64, E).

"Nestling-down" covers newly hatched birds in some cases. This covering is very transitory; it persists only for a short time and is then pushed off at the tips of the developing permanent feathers.

The "powder-down" feathers of the Parrot and other birds are of the nature of down feathers whose barbs degenerate into a powdery mass. Their use is obscure. Possibly the powder may serve to keep the other feathers clean.

Filoplumes.

The third class of feathers is that of the *filoplumes*. They are little thread-like feathers with a small tuft at the top (Fig. 64, F). They are not visible until a bird has been plucked ; it is then seen that they occur all over the body, between the covert feathers. In preparing a bird for the table these feathers are singed after plucking.

Development of Feathers.

A feather develops from the epidermal layer of the skin only. The skin is made up of two layers ; the outer is the epidermis, and the inner is the dermis (p. 220). The epidermis itself is differentiated into two layers. The inner or Malpighian layer is formed of living cells which are constantly giving rise to new cells. The cells so formed are continually being pushed towards the surface by the new ones that are formed. Gradually they become dead and horny, and eventually get worn away at the surface. This horny outer layer is termed the *corneous layer*, or *stratum corneum*.

In the development of a feather a papilla of skin projects. The skin surrounding it sinks and thus forms a little moat which is termed the *feather follicle* (Fig. 65). The papilla, or feather-germ, then continues its development in this follicle. It consists of a central living core of dermis ; surrounding this is the Malpighian layer from which the entire feather is formed. The stratum corneum produces only a sheath, which the feather bursts through during development.

In plucking a fowl it is possible to examine the later stages of developing quill feathers. Very young ones show the quill only ; in older ones the vane is developing at the top of it. When a feather is pulled out a milky juice exudes, which is the pulp formed from the dermis.

As soon as the feather is mature the living core, that is, the dermal portion, retreats down the quill. The retreat is intermittent, and thus little cones or caps are left (Fig. 64, A). It should be noted that the feather is entirely epidermal ; the dermis forms only a nutritive pulp, and is withdrawn from the fully formed feather.

In their origin, therefore, feathers resemble the scales of reptiles. It is sometimes stated that the feather has been evolved from a reptilian epidermal scale by the fraying out of its distal portion. No connecting links between scales and feathers have, however, been discovered, and the origin of feathers is therefore still obscure.

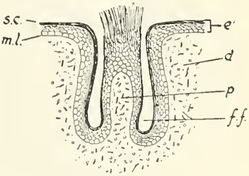


FIG. 65.—Diagram to show the development of a feather. *d.*, dermis ; *e.*, epidermis ; *f.f.*, feather follicle ; *m.l.*, Malpighian layer ; *p.*, pulp ; *s.c.*, stratum corneum.

Feathers must of necessity get worn away and fresh ones must take their place. Moulting at regular intervals has become a fixed habit. Most birds moult once a year after the breeding season, but with some the moulting is more frequent. It usually spreads over a considerable period of time.

The Moult.

An argument against the possible evolution of feathers from reptilian scales is seen in the method of moulting. Reptiles moult the dead outer portion of the epidermis only, that is, the stratum corneum, whereas in birds it is the whole feather, formed from the Malpighian layer, that is cast off.

New feathers arise in already existing follicles. The first to grow after the "nestling-down" originate at the base of the same papillæ as the down. They carry the down up as they develop, and eventually shed it at their tips. Later feathers, however, arise from new papillæ in already existing follicles. New feathers arise while the old ones are still growing. When an old feather finally falls off its papilla atrophies.

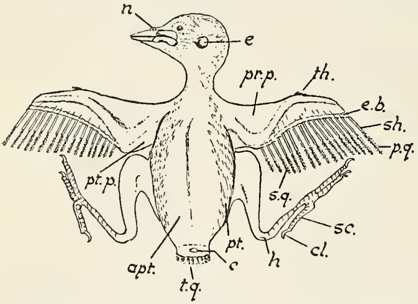


Fig. 66.—A nestling Sparrow. *apt.*, apteria; *c.*, cloaca; *cl.*, claw; *e.*, ear tube; *e.b.*, elastic band; *h.*, heel; *n.*, nostril; *p.q.*, primary quill; *pr.p.*, propatagium; *pt.p.*, postpatagium; *pt.*, pterylæ; *sc.*, scales on foot; *sh.*, sheath of quill feather; *s.q.*, secondary quill; *th.*, thumb feathers; *t.q.*, quill feathers of tail.

Distribution of Feathers.

Feathers do not usually occur all over the surface, but are distributed in definite tracts. These feather-tracts, or *pterylæ*, can be observed in a plucked fowl or, better still, in a nestling before the feathers have covered the body (Fig. 66). The bare patches between the pterylæ are termed the *apteria*.

It happens often in the spring that one picks up, in the garden, a young Sparrow that has died by falling from the nest. Such a little bird is useful for studying the feather-tracts and may be preserved indefinitely in a 2 per cent. solution of formalin.

The nestling Sparrow is useful, too, for the study of the wings.

The Wings.

The wing is seen to be made up of the three joints characteristic of the vertebrate limb (p. 208). These three joints cannot be brought into one straight line even when the wing is stretched to its full extent. This is prevented by two folds of skin, the *propatagium* and the *postpatagium*. The propatagium stretches across the bend of the elbow connecting the arm and forearm on the anterior or pre-axial side; the postpatagium, which is smaller, stretches across the armpit. No separate digits are distinguishable; the thumb only is marked off as a little knob.

The modification of the fore-limb into an organ of flight has been accompanied by the loss, or fusing together, of the bones of the individual digits, and of those of the palm and wrist. Such fusion has given strong support for the powerful flight feathers. Externally only the thumb remains as a separate entity. Dissection shows the bones of two other separate digits and a large compound bone described by Sir Arthur Thomson as "half of the wrist and the whole of the palm." In Archæopteryx reduction had not gone so far (Fig. 61). In this case three separate digits still remain, and these are all tipped with claws.

In the nestling's wing under observation covert feathers are not yet developed—the young quills are either still enclosed in their sheaths or just emerging from them. The quills are borne on the post-axial edge of the hand and fore-arm only; the primary quills are on the hand, and the secondary on the fore-arm. The number is constant for any species. The Dove has eleven quills on the hand and twelve on the forearm; in the Sparrow there are nine primary and eight secondary quills (Fig. 66). A delicate elastic band connects the bases of the quills. This is a provision that prevents their displacement with reference to each other and brings the wing back into position after it has been extended (Fig. 66, *e.b.*).

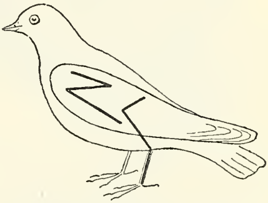


FIG. 67.—Outline of bird to show position of limbs.

The wing of a mature bird should next be studied. When it is at rest the joints of the limb are folded on one another in the form of a Z (Fig. 67). The arm points backward from the shoulder, the forearm forward, and the hand backward. The tip of the wing is thus formed by the primary quills, which converge at their distal ends and bring the whole wing to a point. Next comes the row of secondary quills, and these are followed by the covert feathers of fore-arm and arm (Fig. 62).

A small bunch of feathers which consists of a few small quills and coverts occurs on the thumb (Figs. 62 and 68). These are sometimes termed the "bastard" wing, but are better described from their place of origin as the "thumb" feathers. The student should become thoroughly familiar with the position of the various parts of the right and left wings both at rest and extended.

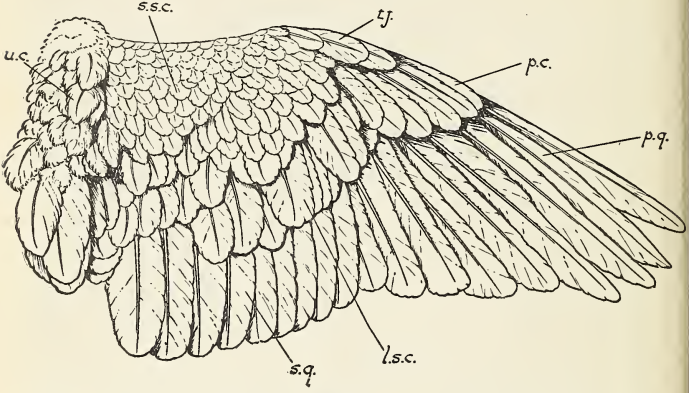


FIG. 68.—Right wing of Pigeon extended. *l.s.c.*, large secondary coverts; *p.c.*, primary coverts; *p.q.*, primary quills; *s.s.c.*, smaller secondary coverts; *s.q.*, secondary quills; *t.f.*, thumb feathers; *u.c.*, coverts over upper part of arm.

Points which have been observed in the individual feathers should now be correlated with their position in the wing. Since it is the distal primary feathers that form the cutting edge of the wing in flight, it follows that the difference in the two sides of the vane is more marked here than it is in the secondary feathers (Fig. 68).

The primary feathers are of great use for steering and for changing direction in the horizontal plane; the secondary feathers appear to be more important for the actual stroke.

Flight.

The movement of the wings in flight is as complicated as it is beautiful. They are first raised to an almost vertical position in which the wings are brought right over the back; sometimes they even strike each other audibly. They then strike the air forward and downward. After this they move backward and upward again. During the complete circuit the tip moves through a double loop (Fig. 69).

The movements are brought about by the very powerful breast muscles. These are remarkably well developed and account

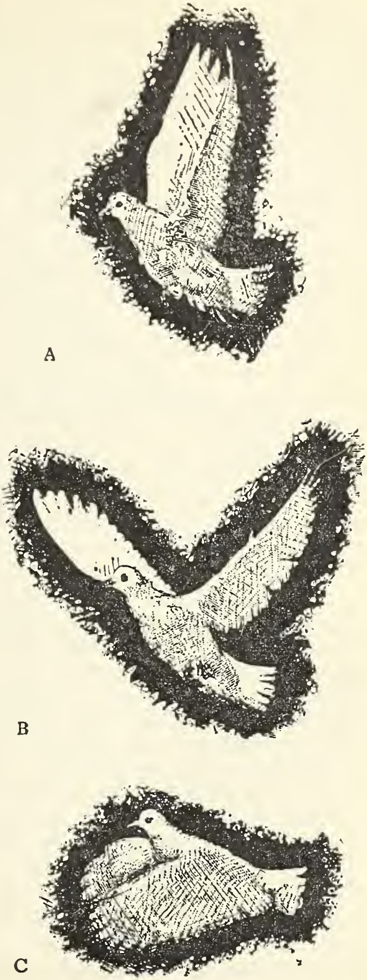


Fig. 69.—A, Position of wings in Pigeon at maximum elevation. B, Wings coming down. C, Wings completely depressed. (After Marey.)

for, on an average, about one-sixth of the entire weight. In birds that are used for the table the "breast" and the keeled bone (the sternum) to which it is attached are familiar. Two muscles on each side of the sternum make up the "breast." Although the two muscles of each side are attached to the same bone, one serves to raise the wing, the other to lower it. The outer larger muscle on each side is attached directly by its tendon to the under side of the bone of the arm (the humerus), and by its contraction the wing is lowered. The second smaller and inner muscle passes by means of its tendon right through an aperture, or foramen, in the shoulder-joint and is attached to the humerus on its upper side. Therefore the contraction of this muscle raises the wing.

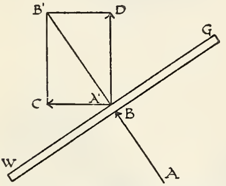


Fig. 70.—Diagram to show forces acting on the wing during flight.

For those who have a knowledge of mechanics some little understanding of the forces which act on the wing during flight may be gained by a consideration of the parallelogram of forces. The wing is brought downward by the action of the powerful breast muscles against the resistance of the air. This resistance has a greater effect on the hinder flexible part than on the front rigid portion of the wing, and, as a consequence, the wing takes an oblique position. The resistant force of the air, which acts at right angles to the plane of the wing, can be resolved into a vertical and a horizontal component; the vertical component tends to buoy the bird up and the horizontal component to carry it forward.

In Fig. 70 W G represents a section through the wing, W being the forward, and therefore lower, edge. The line A B or A^1 B^1 represents the resistance of the air which is equal to the downward pressure of the wing. The direction of the line is at right angles to W G, and the length represents the amount of the force. A^1 B^1 can be resolved into a vertical component A^1 D which lifts the bird and a horizontal force A^1 C which drives it forward.

Flight is not of course such a simple matter as this. The varying convexities of the wing and other important factors have to be taken into account.

When the wing is brought downward it acts as one large expanded plane, impermeable to air. All the remiges are kept in position by the stretched elastic band at their bases, and their quills are covered with coverts so that no air can get through. The interlocking of the barbs makes the vanes, too, impenetrable. Increase in wing surface is produced by the stretching of the membranes between the joints, and a very efficient " plane " is thus produced.

As the wing is brought upward for the next stroke the elastic band relaxes, thus allowing the air to slip between the feathers and the area of the wing is reduced ; resistance is still further lessened owing to the convex shape of the upper surface, which enables the air to slip off it easily.

In addition to what may be described as the ordinary mode of flight by movement of the wings, two other methods must be briefly referred to.

Quite the simplest mode is that of " gliding " with wings outstretched but not flapped. A bird can only begin a glide if it has first attained a certain velocity, or if it is at a height, or if it can be carried by the wind. In this progression is seen what is probably the most primitive method of flight. To quote from Prof. A. J. Thomson (*Biology of Birds*) :

" Given a spare muscular type of body, good breathing, a strong heart, perfect digestion, and rich blood, it is natural to expect active habits—running, jumping, climbing, and parachuting from tree to tree. An examination of a bird's wing shows, in varied development, a web or skin (patagium) extending from the shoulder-joint along the upper or preaxial margin of the arm. It is possible that this was the incipient wing with which primitive birds started, and that they raced along the ground as bipeds, taking occasional skimming leaps, helped by strokes of the somewhat webbed fore-limbs and balanced by the outstretched tail. It is more than a guess that birds had to walk as bipeds before they could run, and that they had to leap before they could fly. . . . After a period of terrestrial life, birds became, no doubt, arboreal, and after a period of arboreal apprenticeship in which the fore-limbs were mainly used as parachutes they acquired true wings—striking the air. The point to be considered is that the assumption of a bipedal mode of progression . . . implied an emancipation of the fore-limb from the task of being a supporting organ, and opened up the possibility of a new function, namely, flight."

A third method of flying is that of sailing, or soaring, as an Albatross sails round a ship ; it circles and circles without apparently moving its wings or losing velocity. This method of flight appears to be impossible in the absence of wind, but its action is imperfectly understood.

The structure of a bird's trunk shows many important modifications which can be correlated with its life both in air and on land. In form it is somewhat boat-shaped with a well-developed keel. Lightness and rigidity have been gained. The former has been achieved partly by the extreme lightness of the bones themselves and partly by the air contained in them. Rigidity is produced by the fusing together of some of the vertebræ.

Trunk.

The question of balance when standing or walking is a very delicate one, since a bird has but two legs for the purpose and has not achieved the upright position characteristic of man. The leg is of the usual vertebrate type (p. 212). In the walking or standing position the knee is bent forward, the heel backward (Fig. 67). Thus balance is maintained; the leg is never straightened completely. The thigh is hidden beneath the skin ; the shin (shank or drum-stick) is covered with feathers ; occasionally the foot is covered with feathers too, but in the Dove, as in the majority of birds, scales similar to those found on reptiles cover the foot from the ankle. Another bit of evidence of the bird's reptilian ancestry is thus afforded.

Legs.

A bird walks on its toes, the rest of the foot being raised above the ground. The number of toes never exceeds four ; they all terminate in claws. Generally, in the case of perching birds, the big toe is directed backward and the other three forward ; in a few cases, as in the Owl, the Cuckoo, and the Woodpecker, two toes are directed backwards (Fig. 72, *c*).

This arrangement of the toes in opposite directions enables a bird to perch, and it is well known that those that roost on perches never fall off in their sleep. The grip of the toes round the support must therefore be mechanical. This grip is produced by tendons which pass from the toes, along the under side of the foot through the back of the heel, and join the muscles up the back of the leg. When the bird sits down on the perch the knee is bent forward and the heel backward by the animal's weight, and thus the actual act of perching tightens up the tendons and causes the toes to grip the perch more securely (Fig. 71).

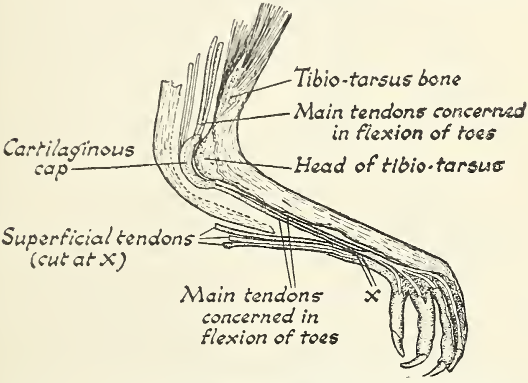

Tibio-tarsus bone
Main tendons concerned in flexion of toes
Cartilaginous cap
Head of tibio-tarsus
Superficial tendons (cut at X)
Main tendons concerned in flexion of toes
X

FIG. 71.—Foot of domestic fowl dissected to show perching tendons. (After Dakin.)

Just as the beaks of birds are indicative of their habits, so, too, are their feet (Fig. 72). They show adaptations for varied forms of progression and also for the catching and carrying of food. The webbed foot of the Duck and other strong swimmers is familiar. By the powerful action of the leg tendons the Owl and the Eagle are enabled to carry their prey with their feet.

Tail. In reptiles the tail is long. In Archæopteryx it is still long, but it has a row of feathers down each side (Fig. 61). In the modern bird the tail is reduced to a mere stump on which the quill feathers are arranged in a horizontal plane, their bases being covered and protected by covert feathers. The rectrices, or quills, of the tail differ from the remiges of the wing in being flat, symmetrical on both sides of the shaft, and more flattened at the tip of the vane. They move independently of one another in the horizontal plane, so that the tail can spread out fan-wise. The tail also moves as a whole in the vertical plane. The functions of the tail are to preserve balance and also to steer in the vertical plane. A bird that has lost its tail quills can still fly, but does so erratically; it finds it difficult to ascend and descend at will. When a bird "cocks" its tail during flight, the air from the down stroke of the wing strikes it underneath and it descends; if, on the other hand, the tail is depressed, the air strikes it above and the bird rises.

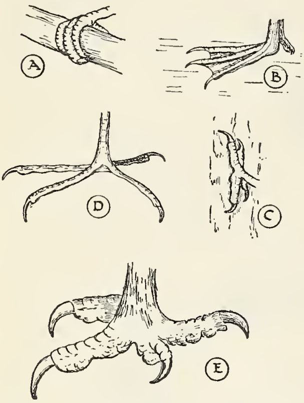


Fig. 72.—Types of Feet. A, Dove: adapted for perching, three toes directed forward and one backward. B, Duck: webbed foot adapted for swimming. C, Woodpecker: climbing bird, two toes directed forward and two backward. D, Heron: the spreading toes of the wading bird which give large base for support. E, Eagle: the sharp curved talons of the bird of prey.

Respiration.

With Birds, as with Insects (p. 63), muscular contraction in the act of respiration brings about expiration, not inspiration. In Mammals, of course, the reverse is the case. A quickly running man is apt to get "out of breath," but the breathing of a bird is a help to its movement, and this is of great importance to such a swiftly-flying creature.

The lungs are fixed to the ribs and do not expand when atmospheric air is taken in, as the lungs of mammals do. The extensible area is provided by large air-sacs which are attached to the lungs and act as reservoirs for the inspired air. The lungs have, however, a large internal absorptive surface through which oxygen is taken in and carbon dioxide eliminated.

In the passive act of inspiration air passes into the lung and also fills the air-sacs; at expiration the lungs are compressed so that the deoxygenated air is got rid of and the lungs fill up again from the air-sacs. The lungs thus receive fresh air both at inspiration and at expiration, and this may to some degree explain the high body-temperature.

That muscular contraction produces expiration and that inspiration is the recoil is proved by the fact that in a dead bird the air-sacs are always filled with air.

A pair of Doves afford material for the study of habits connected with reproduction.

Reproduction. Eggs are laid more or less intermittently all through the winter, but such eggs have not been fertilised, and no desire to sit on them is evinced by the parents. In early spring the sexual impulse returns and the eggs are fertilised.

Internal fertilisation is the rule among birds. It should be remembered that in the case of the frog the eggs were laid first and then fertilised. This method, suitable enough for eggs that are to be deposited in water, is no longer a safe one when they are laid on land; thus it has come about that the conquest of the land is accompanied by internal fertilisation.

In spring the birds show a desire to pick up scraps for nest-building. They should be supplied with dried grass, cotton wool, feathers, and any suitable material, and a nesting-box should be affixed to the cage. Both parents take part in building the nest.

Two eggs are laid, the second being deposited about twenty-four hours after the first. They average an inch in length and are cream in colour.

A brief comparison may be made between the egg of a bird and that of a frog. Since the egg of the former is laid on land and not buoyed up by water, and since also it has to support the weight of the sitting parent, some strengthening envelope is necessary; this is provided by the egg-shell.

A further difference is seen in the much larger supply of food yolk contained in the bird's egg. This supply is necessary because the whole development of the embryo takes place within the egg-shell. When it is hatched, the little bird is essentially like its parents.

Both parents take turns in sitting, and the period of incubation is about sixteen days.

The Doves, when hatched, are quite naked. They are looked after by both parents for a while and the food is taken by the babies from their parents' mouths.

Several broods are reared during one season, and often the mother is sitting on two fresh eggs before the first pair of babies are off her hands. In this case the male tends the nestlings for a while. Soon there comes a time when he, too, deems them old enough to look after themselves and refuses to feed them further. One or two days of much crying on the part of the young often follow, until they realise the uselessness of importuning their parents further. It is most important at this time that only fine-grained food should be put into the cage. An attempt to swallow large grains, such as maize, may prove fatal to the young birds.

Migration.

Most birds appear to be more or less migratory, and the impulse to migrate is instinctive. Probably it originated as a means of circumventing the rigours of winter, this circumvention being made possible by their power of flight. Such a course was impossible for their non-flying ancestors.

To-day Amphibians must needs bury themselves in some snug corner and sleep during the winter. Reptiles, speaking generally, are found only in tropical countries. Birds, alone, can escape the winter by flying to a warmer clime.

The advent of cold and the accompanying scarcity of food drive them southward in the autumn. The causes underlying their northward migration in the spring are not so obvious; it has the advantage of enabling breeding to take place and the young to be reared under more rigorous conditions; a further advantage is that it gives a larger number of hours of daylight for the catching of food, which must be an important consideration when a large family of nestlings has to be provided for.

How birds find their way is, at present, an unsolved problem. It is certain that at times they return to the same nesting quarters year after year. There is no doubt either that they are able to achieve very great velocities and fly almost unbelievable distances.

PRACTICAL WORK

The general external morphology of birds can be studied from any caged birds that are available, preferably large Birds such as Doves or, failing these, domestic Fowls.

Feathers of various kinds and also the wings of Pheasants, Partridges, and other birds, can be procured from a poulterer. Wings got in this way will always be cut off at the elbow-joint, but, since the flying feathers are attached to the fore-arm and hand, these easily obtainable wings are of great use.

To observe the structure of the barbs a small piece of a feather must be placed in spirit for a short time and then examined first under the low and then under the high power of the microscope.

Different stages in the development of a feather can be seen on a plucked fowl when the mature feathers have been removed.

If a nestling is available it may be preserved in 2 per cent. formalin and used for the study of feather tracts, wing structure, ear-holes, and other structures. For the better study of the wing the specimen should be pinned out on a piece of cork with the wings extended.

CHAPTER XI

MAMMALS

The morphology of a typical Mammal and the functions of its various organs are studied in detail in Section III. This chapter deals with the chief characteristics of Mammals as a class and with the variations that occur in the different groups.

Birds and Mammals comprise the two classes of warm-blooded Vertebrates.

Comparison of Birds and Mammals.

Mammals attain a larger size than Birds, for bulk is a great disadvantage to a flying animal. Among the Mammals themselves the largest animals are found among those that are aquatic, for in their case the weight is supported by the water.

Since Birds and Mammals have the power of keeping a constant temperature, the habit of hibernation is no longer necessary as it is for Amphibians and Reptiles. It does still occur, however, in some few Mammals.

The range of Mammals is necessarily more restricted than that of Birds, which circumvent the adverse conditions of winter by flight. It follows, therefore, that Mammals are dominant in temperate regions. The animal-life of the Arctic zones is almost entirely bird-life. Large cold-blooded animals—the Snakes, for instance—are characteristic of the Tropics.

Birds and Mammals alike have evolved from Reptilian ancestors, but along divergent lines. Since Man belongs to the Mammals, it is natural to regard this class as the highest of animals. In many ways it undoubtedly is so ; in development of brain and in power of thought Man is pre-eminent. Structurally, however, Mammals do not far surpass the Birds ; in fact, in many ways the evolution of the Bird, as an adaptation to its special mode of life in air, has progressed farther than the evolution of the Mammal, as an adaptation to its special mode of life.

Just as feathers are the typical outgrowths of the skin of Birds, and scales of the skin of Reptiles, so *hairs* are typical of Mammals.

Characteristics of Mammals—Hairs.

All mammals are more or less covered with hairs. Their origin is similar to that of feathers, but the dermal pulp does not extend up into the hair as it does into the feather. The dermal papilla remains at the base of the hair follicle, and dead epidermal cells are piled on the top of it, making a solid, multicellular hair. Another point of difference is that an oil-gland opens into each hair follicle ; these glands lubricate the hairs, thus giving them their glossy appearance and their power of keeping the body dry (p. 221).

Hairs vary very much in character. They are usually circular in section ; sometimes, however, they are ribbon-like, and then the hair is curly. Frequently they tend to mat together, and "wool" results. There is great variety, too, in their thickness and their length ; they may form a long, hairy coat covering the whole body, or be restricted to just a few bristles.

Hairs, like feathers, are shed periodically. In some cases the summer and winter coats are different in length and thickness and even in colour.

Also hairs, like feathers, keep the body warm by preventing too rapid loss of heat from the skin.

The Sense-organs.

The general alertness and mental superiority of mammals is correlated with a proportionately high development of the external parts of the sense-organs. This is particularly true of the nose and ears.

The nose is nearly always large, naked, freely movable, and very moist.

In most mammals the external ears, or *pinnæ*, are freely movable and act as receivers for gathering up the waves of sound. The external ear is a mammalian characteristic.

Dentition.

The teeth are very highly developed, and their character, in any particular case, indicates the kind of food that the animal eats. In a few cases all the teeth are of the same nature, or *homodont*. Generally there is division of labour ; the teeth are used for different purposes and are consequently different in structure, or *heterodont*.

As a rule there are two successions of teeth. These are the *milk* and *permanent* dentitions.

The teeth cease growing in most cases after a certain definite time. The dermal papilla that feeds each tooth becomes constricted to a tiny neck, the base of the tooth narrows, and is then prolonged into one or two roots which become firmly fixed in the socket.

In a few cases there is no constriction at the base, and growth of the tooth continues throughout life, by means of a persistent pulp.

There are four distinct types of teeth.

In the front of the mouth are the *incisors*, or cutting teeth. These are simple teeth with a single root. The crowns are chisel-shaped and suitable for cutting and cropping grass.

On either side of the incisors are the *canines*. These also have single roots, but their crowns are conical and pointed. Their function is the tearing of flesh.

The *pre-molars* follow, and behind them are the *molars*. These teeth are more complicated and have two or more roots. The crowns may be sharp-edged, bearing one or more cusps, in which case they are useful for severing flesh from bone. They may be broad and ridged and thus suitable for grinding. There are only pre-molars in the milk dentition ; molars are not produced until the permanent teeth are formed.

In the typical mammalian dentition, that is the one probably possessed by the common ancestral type, there are, on either side of the upper and lower jaws, three incisors, one canine, four pre-molars, and three molars. The complete dentition is therefore forty-four. It is convenient to express this as a formula :

$$2\left[\mathrm{I}\,\frac{3}{3}\qquad \mathrm{C}\,\frac{1}{1}\qquad \mathrm{PM}\,\frac{4}{4}\qquad \mathrm{M}\,\frac{3}{3}\right]=44.$$

In this formula one side only of the mouth is given. The numbers above and below the lines represent the teeth of upper and lower jaws respectively.

Interesting modifications of this dental formula will be studied in connection with different types of feeding.

Limbs.

It will be remembered that the original vertebrate limb was used only for progression, not for support. Flexibility of joints was therefore the first necessity. As soon as limbs were used for support also, greater rigidity was essential. The evolution of the limb is therefore bound up with these divergent functions : flexibility must be sacrificed to rigidity ; rigidity to flexibility. As a result of various modifications, rapid movement in one plane was made possible. Speed has further been achieved by the raising of the heel, so that the weight is carried by, and the animal progresses on, the toes. In extreme cases progression is not even on the toes, but merely on the toenails or hoofs.

An animal that walks on the sole of the foot is termed *plantigrade* ; when progression is on the toes it is *digitigrade* ; if the hoofs only are used it is *unguligrade* (Latin *ungula*, a hoof). Some animals are *sub-plantigrade* : they keep the whole of the sole of the foot on the ground when resting, but raise it when walking.

The trunk is generally more or less in a horizontal position, supported by the four limbs (*quadrupedal*). The joints of the limbs are seldom in a straight line. The fore-limb is bent backward from the shoulder, and forward from elbow to wrist, and from wrist to digits. In the hind-limb the direction is forward from hip to knee, backward from knee to heel, and again forward to the digits. Thus the elbow- and the knee-joints always approximate to one another.

Although in the vast majority of cases the limbs are used for support and progression on land, they do in some cases function in other ways. This is particularly so in the case of the fore-limb, which becomes modified for swimming or flying (Figs. 97, 98, 99, and 104). The extremities of both fore- and hind-limbs are, in some cases, converted into prehensile, or grasping, organs (Figs. 76 and 104).

There are many anatomical points in which Mammals differ from all other Vertebrates. One outstanding characteristic is the muscular *diaphragm* of the mammal. This separates the chest from the abdominal cavity. It is of great importance in respiration, making possible the perfection of air-breathing which the mammals, as a group, have attained (p. 176).

Respiration.

The pronounced difference, however, between mammals and all other animals is the relation between parent and offspring.

Reproduction.

It has already been noted that the parental care shown by birds is ahead of that found in the classes below them. The mammal, however, far outstrips the bird in the care of its young.

Internal fertilisation takes place as in birds. The mammalian egg is extremely small, varying from $\frac{1}{120}$ to $\frac{1}{200}$ inch in diameter. The egg is not set free after fertilisation, but develops within a cavity in the mother, termed the *uterus*.

A few days after fertilisation actual organic connection is set up between the parent and the developing embryo. The tissue that forms the connection is known as the *placenta*. Through the blood capillaries in this tissue, food in solution and oxygen for respiration pass from the parent to the offspring.

This prenatal period is termed *gestation*. It varies greatly in length in different mammals.

The degree of helplessness of new-born mammals also varies very much. Some are practically independent as soon as they are born, while others are blind and helpless. All are, however, dependent upon the mother for their food. This is supplied by the *mammary-glands* in the form of milk.

Doubtless the long period of infancy, during which the young are dependent on the mother, both for preservation and for food, has been one of the potent factors in the evolution of the finer senses of the higher mammals.

Structural Modifications.

Modifications in structure are associated with their different habits of life : The character of the coat varies with climate ; thus it differs in the Tropical, Temperate, and Arctic zones ; it differs, too, in land and water animals. Limbs are modified according to need ; sometimes for fleetness, sometimes for greater strength, sometimes for purposes other than support and progression on land. Teeth are modified in accordance with the nature of the food. Weapons, offensive and defensive, are evolved.

These are some of the determining points in framing a system of classification.

CLASSIFICATION OF MAMMALS

MAMMALIA

- Sub-class I. Prototheria
  - Includes Duck-billed Platypus and Spiny Ant-eater
- Sub-class II. Theria
  - Section A. Metatheria (Marsupialia)
    - Two Orders include:
      - Opossum
      - Kangaroo
      - Wombat
      - Wallaby
  - Section B. Eutheria
    - Nine Orders
      1. *Edentata* include:
         - Sloth
         - Armadillo
         - Scaly Ant-eater
      2. *Cetacea* include:
         - Whale
         - Porpoise
         - Dolphin
      3. *Sirenia* include no well-known animals
      4. *Ungulata*
         - Odd-toed include:
           - Horse
           - Ass
           - Zebra
           - Tapir
           - Rhinoceros
         - Even-toed
           - Ruminants include:
             - Ox
             - Sheep
             - Goat
             - Antelope
             - Giraffe
             - Deer
             - Camel
           - Non-Ruminants include:
             - Pig
             - Hippopotamus
         - Five-toed
           - Elephant
      5. *Carnivora* include:
         - Lion
         - Tiger
         - Fox
         - Dog
         - Cat
         - Hyena
         - Bear
         - Weasel
         - Otter
         - Seal
         - Walrus
      6. *Rodentia* include:
         - Rat
         - Mouse
         - Hare
         - Rabbit
         - Squirrel
         - Beaver
         - Porcupine
      7. *Insectivora* include:
         - Mole
         - Shrew
         - Hedgehog
      8. *Chiroptera*:
         - Bat
      9. *Primates* include:
         - Lemur
         - Monkey
         - Baboon
         - Gibbon
         - Orang
         - Chimpanzee
         - Gorilla
         - Man

The Table of Classification should be studied in connection with the following descriptions.

Classification. The Class, Mammalia, is divided into two sub-classes, the Prototheria and the Theria.

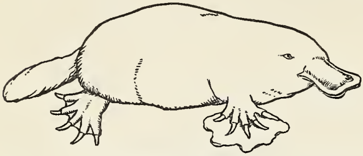


Fig. 73.—Platypus. Sketch drawn from museum specimen showing clawed and webbed feet.

Prototheria. The Prototheria include the Duck-billed Platypus (Fig. 73) and the Spiny Ant-eater. Both these animals occur in Australia and Tasmania, and the latter is found also in New Guinea. They are primitive Mammals. Like Birds and Reptiles, they lay eggs, but like all other Mammals they suckle their young.

Prepared specimens of the Platypus are in many museums. It is a curious-looking creature with a muzzle rather like a Duck's bill. Its fore-feet are clawed and webbed and thus adapted both for burrowing and swimming. It lives by lakes and rivers, feeding on larvæ which it finds in the mud at the bottom of the water.

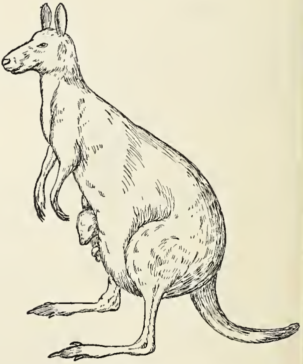


Fig. 74.—Kangaroo. Sketch drawn from museum specimen showing position of pouch.

Theria. In the sub-class Theria there are two sections, the Metatheria and the Eutheria.

A—Metatheria. The Metatheria, or Marsupialia (Latin *Marsupium*, a pouch), include the Opossums, Kangaroos, Wallabies, and Wombats. All these animals have a pouch, in which the teats of the mammary glands are situated (Fig. 74).

In all there is placental connection between the mother and the embryo, but only part of the development of the embryo takes place within the uterus. Birth occurs before the offspring can look after itself. It manages to crawl into the pouch or, according to some authorities, the mother herself transfers it to the pouch with her lips. It then attaches itself to a nipple. It is not yet able to suck, and the milk is forced into it from the mother by the muscles that surround the mammary glands. Although the baby is receiving nourishment from the mother it is breathing independently. When development is complete it frees itself from the nipple, but remains a little while longer in the pouch.

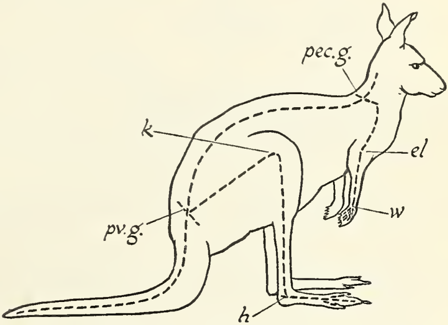


FIG. 75.—Kangaroo. Outline, to show position of limbs and use of tail for support, with dotted line to denote skeleton. *el.*, elbow ; *h.*, heel ; *k.*, knee ; *pec.g.*, pectoral girdle ; *pv.g.*, pelvic girdle ; *w.*, wrist.

The Kangaroo lives on the open plains. It feeds on grass and is very destructive to crops. By means of its tremendously long back legs it bounds over the plains. When it is erect it uses its tail as a sort of third leg to give stability (Fig. 75). In leaping the tail is put out horizontally to help in maintaining balance.

In Australasia there are no *native* mammals higher than Marsupials, and this is extremely interesting from the point of view of evolution. There are, it is true, Rabbits, Bats, and Dingoes in this part of the world, but the Rabbit was introduced in recent times ; the Bat has flown there ; the Dingo is frankly a mystery, and, so far, its presence is unexplained.

The geographical inference is, that Australia became separated from the continent of Asia at a time when no mammals higher than Marsupials had evolved. After the separation the Marsupials continued to thrive there, since they never had to contend with other mammalian competitors.

B—Eutheria.

The Eutheria is a very large section and contains all the familiar mammals. The distinguishing characters of its nine orders are concerned largely with differences in limbs, teeth, and hair.

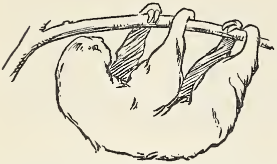


FIG. 76.—Sloth. Sketch made from museum specimen.

1—Edentata.

In the Edentata the teeth are deficient or wanting. The Sloth has long, coarse fur and is most perfectly adapted to arboreal life (Fig. 76). Its hands and feet are modified into mere hooks, and it generally hangs, head downward, from the branches.

2—Cetacea.

The Cetacea include the Whales, Porpoises, and Dolphins. They have taken to an aquatic life and show structural modifications resembling those found in fishes (Fig. 77). They are torpedo-shaped and have no teeth ; external ears are not present ; the fore-limbs are converted into paddles and the hind-limbs are missing ; a dorsal fin and a forked tail have been developed. Particular interest is attached to the tail, because this is flattened *horizontally*, not vertically, as in fishes. The function of the tail, in both cases, is that of propulsion. But the Cetacean must come to the surface to breathe. This necessitates an up-and-down action of the tail instead of a movement from side to side.

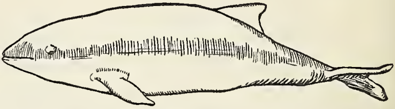


FIG. 77.—Porpoise. Sketch made from museum specimen.

Hairs are reduced to a few bristles round the mouth, and the body-temperature is kept up by a very deep layer of subcutaneous fat or " blubber."

One group of Whales has homodont teeth. In another they are replaced by " whalebone." In this latter case there occur, hanging down like curtains from the palate into the cavity of the mouth, pairs of plates of horny substance. This is the whalebone. The lower edges of the plates are fringed and act as strainers. The food consists of very small prey, taken into the mouth with water. The Whale then raises its tongue against the edges of the plates so that the water trickles out through the strainers and the food is retained.

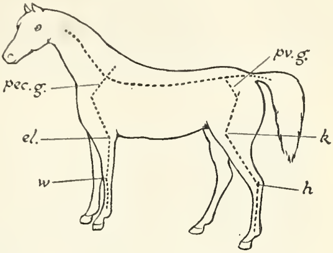


Fig. 78.—Horse. Outline to show standing position (unguligrade) and position of limbs. Dotted line denotes skeleton. *el.*, elbow; *h.*, heel; *k.*, knee; *pec.g.*, pectoral girdle; *pv.g.*, pelvic girdle; *w.*, wrist.

The Cetaceans are all carnivorous and travel in herds, or "schools."

3—Sirenia.

The Sirenia, or Sea-cows, are aquatic vegetarians and superficially resemble the Whale family. There are no common types.

4—Ungulata.

The Ungulata are the hoofed animals. They are terrestrial, and mainly herbivorous. For their preservation they have to depend upon fleetness of foot. Swiftness is attained by lifting the heel and running on the tips of the toes. The feet are much lengthened, so that the heels are raised high above the ground; this is the cause of the popular mistake of referring to the wrist and ankle as "knee" and "hock" respectively (Fig. 78).

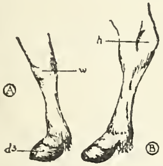


Fig. 79.—Foot of Horse. A, Left front. B, Left back. d^3., third digit; *h.*, heel; *w.* wrist.

The tips of the toes are protected by modification of the nails into broad, horny masses termed *hoofs*, which grow over the sides and ends of the toes (Fig. 79). In these animals, therefore, progression is *unguligrade*. There is no power of grasp in the limbs of any animals included in this order, whose three main classes are distinguished by foot-characters.

The Odd-toed Ungulates include Horse, Ass, Zebra, Tapir, Rhinoceros.

Odd-toed Ungulates.

In this class the foot could be bisected by a line passing through the middle toe. In other words, the axis of the foot runs through the third digit.

The Horse.

In the Horse the third digit is the only functional one. Two others persist, but are much reduced and are applied, like splints, to the large central one. The whole limb has become an organ for quick locomotion in one plane (Figs. 78, 79).

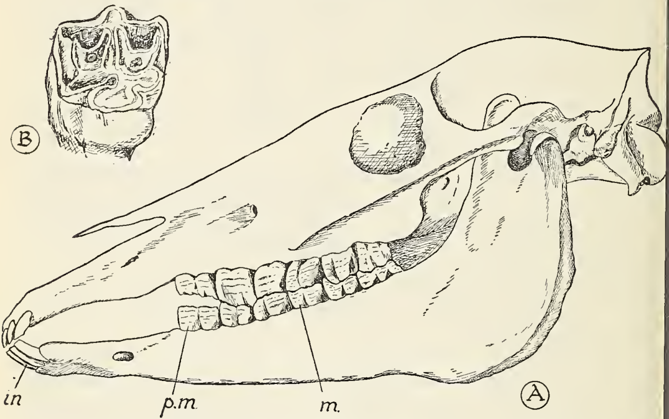


Fig. 80.—A, Skull of a mare to show dentition (canines missing). B, Grinding surface of a premolar. *in.*, incisor ; *m.*, molar ; *p.m.* premolar.

The food of the Horse needs good grinding teeth. Premolars and molars are similar in character and have broad crowns with complicated ridges (Fig. 80). The dental formula is that typical of mammalian dentition :

$$2\left[\mathrm{I}\,\frac{3}{3}\quad \mathrm{C}\,\frac{1}{1}\quad \mathrm{PM}\,\frac{4}{4}\quad \mathrm{M}\,\frac{3}{3}\right]=44.$$

The first pre-molar is merely vestigial and is either soon lost or absent altogether in the lower jaw. The canines, too, are generally missing in the Mare.

The Horse is particularly interesting because so much is known of its past history. Owing to a marvellous series of fossils found in the Tertiary Beds of America, the evolutionary history of the Horse, for about the last 5,000,000 years, has been traced in greater detail than has been possible for any other animal. Sufficient links have been found to make the story fairly complete.

The Tertiary Era has been divided into five rock systems: Eocene, Oligocene, Miocene, Pliocene, Pleistocene.

The earliest fossil record of a horse-like animal comes from the Eocene deposits. It is that of a little animal about as large as a Hare, having four complete digits on the front limbs and three on the back. On all of these digits it walked, although there are already signs of some interlocking in the bones of the wrist and the ankle. Its teeth are simple. It lived at a time when the climate of North America was very moist. The land was covered with forests. There were many streams and much lush grass. There was, therefore, plenty to eat and but little necessity for swift running. This fossil animal has been named Eohippus.

Gradually the swamp conditions changed to those of the grassy plain. Along with this change in environment came a gradual change in the ancestors of the modern Horse. Food was getting more and more scarce, so that ever-increasing distances had to be covered in order to get enough. The quality of the food was altering, too, so that much more mastication was needed.

In the Oligocene epoch came an animal about as big as a Sheep. It has been named Mesohippus. It only had three toes on each foot, and the middle toe was larger than the others. Its teeth had more complicated grinding surfaces.

The Miocene deposits give Protohippus and others. These are much larger animals, being about the size of a Donkey. In them the middle toe is much the largest and bears the whole weight. The grinding surfaces of the teeth have become much more complex. During the Miocene period, North America was covered with dry grass prairies. Not only was food still more difficult to get, but it was less utritious when obtained.

In the Pliocene deposits still larger animals occur. Hipparion and others are as large as a Pony. They have little remains of any but the middle toes, and their teeth have most complicated grinding surfaces.

A complete series of fossils has thus been obtained which starts with little Eohippus of the Eocene era and leads right on to the Pleistocene period and the modern Horse.

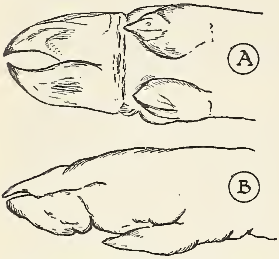


Fig. 81.—Pig's trotter. A, Under surface. B, From side.

Even-toed Ungulates.

In the Even-toed Ungulates the third and fourth toes are equally developed, and the axis of the foot runs between them (Figs. 81 and 82). The second and fifth digits are small, and as a rule do not touch the ground (Fig. 83). Here, again, a rigid limb, capable of rapid movement in one plane, has been produced. In the odd-toed animals the result is achieved by the strong development of the central digit. In the even-toed group two digits develop equally, but they act as one, since the bones are fused, except for the cleft in the hoof.

Thus there results a cloven-hoof, particularly well suited for life in marshy places. As the two portions of the hoof can be spread out, the animals are less liable to sink in the mud.

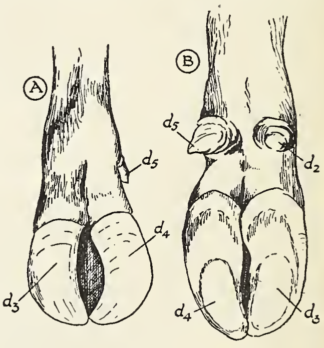


Fig. 82.—Cloven hoof of Ox. A, Upper surface. B, Lower surface. d_2., d_3., d_4., d_5., second, third, fourth, and fifth digits.

The Even-toed Ungulates are divided into Ruminants and Non-Ruminants.

The Ruminants include the Camel. Ox, Sheep, Goat, Antelope, and Giraffe.

Non-Ruminants include the Pig and Hippopotamus.

Ruminants.

Ruminants (Latin *rumen*, throat) all "chew the cud." This habit may have arisen as a defence. They are all herbivorous animals, and in the wild state would have many enemies. It must have been very convenient to be able to eat hastily and then proceed with the digestion of the food later, in some place of safety.

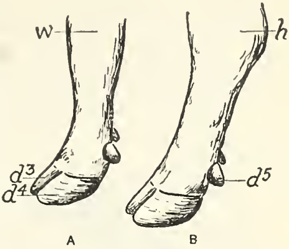


FIG. 83.—Foot of Ox. A, Front left. B, Back left. To show standing position (unguligrade) and lifting of wrist and heel. d_3., d_4., d_5., third, fourth, and fifth digits; *h.*, heel; *w.*, wrist.

Sheep.

The Sheep will serve as an example to illustrate dentition and digestion. It has no incisors or canines on the upper jaw. In the place of these there is a horny pad, against which it clips off grass with the lower incisors (Fig. 84). The grass is swallowed immediately, together with copious saliva, and passes into the first division of the stomach, which is the *rumen*, or *paunch*; from this it passes into the second division, the *reticulum* or *honey-bag*. The stomach is

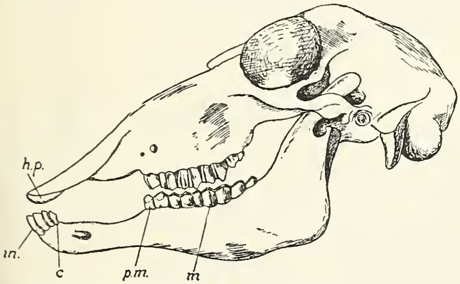


FIG. 84.—Skull of Sheep to show dentition. The skull is freshly prepared, and the horny pad is still attached to the upper jaw. Canine teeth in the lower jaw are similar to the incisors, and in the same series. *c.* canine; *h.p.*, horny pad; *in.*, incisor; *m.*, molar; *pm.*, pre-molar.

complicated, consisting of four separate compartments (Fig. 85).

When the animal has finished grazing, it settles down to chew the cud. The food, which has become a little softened in the paunch and reticulum, is returned to the mouth by antiperistaltic action (p. 154). In the mouth it is worked up with more saliva and thoroughly masticated. It is then returned again to the stomach, but, at this second swallowing, the now masticated food goes straight to the reticulum. From this it passes to the third chamber, the *psalterium* or *many-plies*, which acts as a filter. At last it enters the *abomasum* or *reed*, which is the true stomach and secretes the gastric juice.

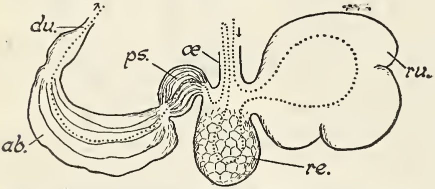


Fig. 85.—Diagram of Sheep's stomach cut open to show the different chambers and the course taken by the food. *ab.*, abomasum or reed; *du.*, duodenum; *œ.*, œsophagus; *ps.*, psalterium or many-plies; *re.*, reticulum or honey-bag; *ru.*, rumen.

The dental formula of the Ruminants is :

$$2\left[\ I\,\frac{0}{3} \quad C\,\frac{0}{1} \quad PM\,\frac{3}{3} \quad M\,\frac{3}{3}\ \right]=32.$$

Another interesting character of Ruminants is the frequent possession of horns and antlers.

Horns and Antlers. These are very special weapons of offence and defence and are specially characteristic of the male. They are formed as outgrowths of the frontal bones of the skull (p. 215). Horns are permanent structures which grow continuously at the base and get worn away at the tip. Antlers, on the other hand, are shed at intervals, and new ones develop in their place.

Giraffe and Camel. The modifications of structure which occur in the Giraffe and Camel are of particular interest. Although the Giraffe has such an enormously long neck (Fig. 86), a neck that enables it to crop young buds and leaves from lofty trees, it still has only the usual seven cervical vertebræ (p. 205).

The Camel's special adaptations fit it for life in the desert. It is able to carry within itself a supply of both food and water. The food consists of one or two dorsal humps of fat. The Arabian Camel, or Dromedary, has one hump only. The Camel of Central Asia has two. Water is stored and carried in little pockets on the walls of the paunch.

The Camel does not walk on its hoofs (Fig. 87). On the yielding desert sand a broader base is needed. The hoofs diverge from one another and behind them is a pad on which the animal treads. Thus the weight is carried, not on the extreme tips, but on the last joints, of the toes.

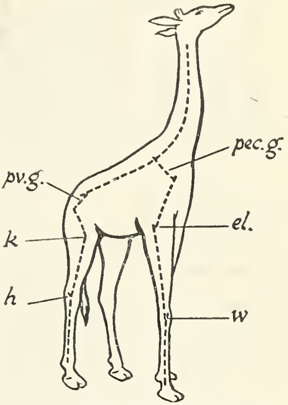


FIG. 86.—Giraffe. Outline showing cloven hoofs (third and fourth digits), great elongation of limbs, and the extent of the limbs that is enclosed in the trunk. *el.*, elbow; *h.*, heel; *k.*, knee; *pec.g.*, pectoral girdle; *pv.g.*, pelvic girdle; *w.*, wrist.

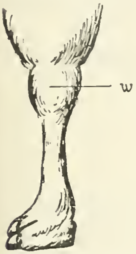


FIG. 87.—Fore-foot of Camel showing pad on which the animal walks. *w.*, wrist.

Non-Ruminants.

The Non-Ruminant group of the Even-toed Ungulates includes the Pig and Hippopotamus. These animals are not so highly specialised as the Ruminants. Living as they do in marshy places, a broad tread is required, and they have four well-developed toes. The Hippopotamus puts all four toes on the ground (Fig. 88). In the Pig the two lateral toes are small and do not reach the ground (Fig. 81).

The Pig is covered with coarse bristles and has a terminal tuft of strong hairs on its tail. Its external ears are large. It has a mobile snout and terminal nostrils. The canine teeth have a persistent pulp and do not become rooted ; they continue to grow throughout life, and form, in the male, large, curved tusks.

The Hippopotamus is a huge, unwieldy creature, with tremendously thick, almost hairless, hide. The "hide of a hippopotamus," in fact! The legs are short and thick. The head is huge ; the nose is expanded ; the external ears are very small. Its food consists entirely of grass and herbage. It feeds at night and spends the day in the lakes and rivers of its African home. It is a good swimmer, notwithstanding its ungainly bulk.

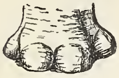


Fig. 88.—Foot of Hippopotamus.

Elephant.

The Elephants make up the third division of the Ungulates. There are two species of Elephant. The Indian Elephant has an elongated head, a concave forehead, and average-sized ears. The African Elephant has a shorter head, convex forehead, and enormous ears.

The skin is very thick and scantily covered with hairs and there is a tuft of hairs at the end of the tail.

The legs are stout and almost straight. They are, in fact, set perpendicularly at the four corners, rather like the legs of a table. The upper parts of the limbs are free from the general skin of the trunk ; this condition is found in no other mammals, with the exception of the Primates (Fig. 89).

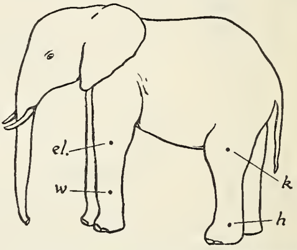


Fig. 89.—Elephant. Outline showing the freedom of the limbs from the body. *el.*, elbow ; *h.*, heel ; *k.*, knee ; *w.*, wrist.

The Elephant is a creature of dense forests and swampy grass jungles, and therefore needs a broad foot. All the feet have five toes. Those of the fore-feet and either three or four of the hind-feet terminate in a broad flat hoof (Fig. 90).

The teeth are particularly interesting. In the male of the Indian Elephant, and in both sexes of the African species, the upper incisors develop into huge weapons of offence, the tusks. They are almost entirely composed of pure dentine, or ivory. Canines are absent. The molars appear in succession, not all at the same time, as in other mammals. Those towards the front of the mouth are the first to break through the gums. When these get worn away they fall out, and the next pair come forward to take their place. There is not room for more than one or two on each side at the same time. In all, there may be as many as six molars on either side (Fig. 91). The dental formula is :

$$2\left[I\,\frac{1}{0}\qquad C\,\frac{0}{0}\qquad M\,\frac{6}{6}\right]=26.$$

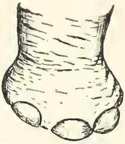


FIG. 90.—Elephant's foot showing the large surface for support. All the toes are embedded in the common integument, the hoofs only remaining separate.

The nose and upper lip are prolonged into a proboscis, or trunk. This is perforated throughout its entire length by the nostrils and has a finger-like process at the end, by which quite small trifles are picked up. The evolution of the Elephant is bound up with that of its trunk, for without the trunk the animal could neither eat nor drink. Owing to the shortness of its neck it cannot get its mouth to the water. The long tusks effectually prevent it from biting directly the herbage on which it feeds. By means of the trunk water is drawn up, then poured into the mouth. The finger-like process at the tip of the trunk picks grass and conveys it to the mouth.

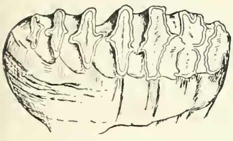


FIG. 91.—Molar tooth of African Elephant sketched from museum specimen.

5—Carnivora. The order *Carnivora* (Latin *Caro*, *carnis*, flesh ; *voro*, I devour) includes many animals that are flesh-eaters. For this reason their digestion is not concerned with starchy food.

The Dog. A Dog "bolts" his food. Mastication, promoting the flow of saliva, is not necessary, because the secretion of the salivary glands acts only upon starch (p. 153). Therefore grinding teeth are not required.

What a Dog needs is a dentition that will enable it to tear the flesh from a bone and also to crack up the bone itself (Fig. 123, D). All his teeth are more or less pointed. The canines are particularly well developed, and the name canine (Latin *canis*, a Dog) has been given to these teeth because of their great development in this group. The canine teeth are much larger than the others; they are curved and pointed, and are very formidable weapons of offence. The crowns of the pre-molars consist typically of a central cusp and two smaller ones with cutting edges. The molars are broad, crushing teeth. The last pre-molar of the upper jaw and the first molar of the lower jaw bite on one another like a pair of scissors. These are termed the *carnassial* teeth.

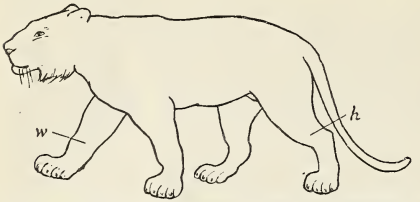


Fig. 92.—Tiger. Outline showing digitigrade method of progression. *h.*, heel; *w.*, wrist.

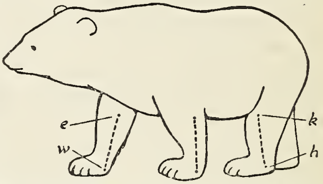


Fig. 93.—Bear. Outline to show standing position (plantigrade) and position of limbs. *e.*, elbow; *h.*, heel; *k.*, knee; *w.*, wrist.

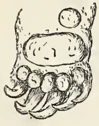


Fig. 94.—Bear. Under surface of paw (palm).

The dental formula of the Dog is:

$$2\left[\mathrm{I}\ \frac{3}{3}\quad \mathrm{C}\ \frac{1}{1}\quad \mathrm{PM}\ \frac{4}{4}\quad \mathrm{M}\ \frac{2}{3}\right]=42.$$

Associated with the flesh-eating habits of the Carnivora is a quick intelligence and often great fierceness. The majority are digitigrade, and have five digits on the fore-limb and four on the hind one (Fig. 92). The Bear is plantigrade (Fig. 93). The digits are clawed (Fig. 94), and in some cases the claws are retractile.

The Dog walks on his toes. He has five digits on the fore-limb and four on the hind one. A rudiment of the first digit, the "big toe," of the hind-limb is seen in the "dew-claw."

On the underside of the toes are soft pads. The claws are curved and not retractile, so that they get blunted by friction with the ground.

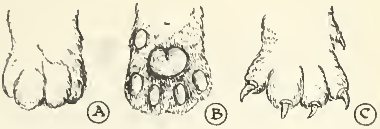


Fig. 95.—Cat's foot. A, Upper surface with claws retracted. B, Lower surface showing pads. C, Upper surface with claws protruded.

The Cat.

The Cat is somewhat highly specialised. It is digitigrade, and its limbs also resemble those of the Dog in number of digits. Unlike the Dog, however, it can use its fore-limbs for seizing. The claws are very formidable weapons of offence; they are large, curved, and very pointed, being kept in condition by their retractile character (Fig. 95). As they are not continually getting worn away they are always well pointed and ready to scratch. Moreover, the Cat is able to approach its prey quietly and stealthily on the soft velvet pads which cover the soles of its digits.

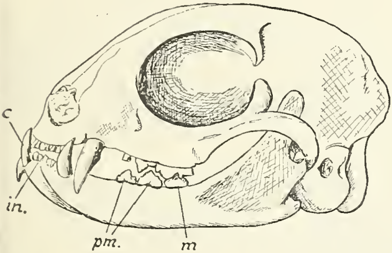


Fig. 96.—Skull of Cat to show dentition. *c.*, canine; *in.*, incisor; *m.*, molar; *pm.*, pre-molar.

Everyone has experienced the rough rasp-like feeling of a Cat's lick. By means of this rasp it is able to clean the flesh off a bone very thoroughly.

Its pre-molar and molar teeth are similar in character to those of the Dog, but they are much reduced in number (Fig. 96). Consequently the jaw becomes shortened and the rounded form, characteristic of the Cat's head, results.

The dental formula is :

$$2\left[I\,\frac{3}{3}\quad C\,\frac{1}{1}\quad PM\,\frac{3}{2}\quad M\,\frac{1}{1}\right]=30.$$

Aquatic Carnivora.

Special modifications occur in members of the Carnivora that have taken to an aquatic life. They tend to have long, lithe bodies, no necks, and short, modified, fin-like limbs that are adapted for swimming. If they have external ears, these are very small. They are, of course, air-breathing animals, and, although they spend most of their time diving about in water, they all come on land to breed.

In the Otter, which is still found in many parts of England, the toes are all webbed, and the tail is somewhat long and flattened.

In the Seal and Walrus the limbs are very short. Except for the foot and the hand they are enclosed within the common skin of the body.

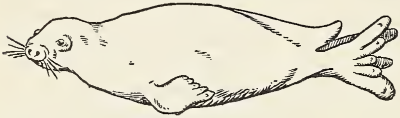


FIG. 97.—Seal. Sketch made from museum specimen.

The Earless Seals, which, as their name implies, have no external ears, are the most completely adapted for life in water. They can only progress at all on land by wriggling contortions of their bodies, when they drag their hind-limbs behind them. Their front limbs are converted into short, stout flippers which are covered with hair and bear nails (Fig. 97).

The Eared Seals, or Sea Lions, have small external ears. In this case the hind-limbs can be flexed forward and so used for progression and support on land. These Seals have flat, triangular front flippers, with neither hair nor claws. It is from this class that sealskin fur is obtained (Fig. 98).

Like the Seal, the Walrus is also able to flex its hind-limbs and so use them for progression. Another interesting point in connection with this animal is the development of the upper canines into huge tusks (Fig. 99). These tusks are not rooted, as are all the other teeth of Carnivora, but continue to grow by means of a persistent pulp, in the same manner as those of the Pig.

6—Rodents. Rodents (Latin *rodere*, to gnaw) are found in all parts of the world, and the order contains more species than that of any other order of mammals. Rodents are mostly small, furry, terrestrial animals and do not show so many modifications of structure as are present in the other orders. They are typically vegetarian, and gnaw their food in a very characteristic way.

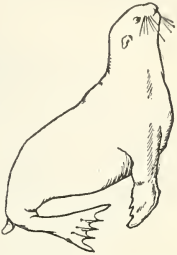


Fig. 98.—Sea-lion. Sketch made from museum specimen.

The Rabbit. The Rabbit is a convenient type to study. Two incisors, well adapted to their work of continuous cropping or gnawing, are present in each jaw. As is usual in the case of incisor teeth, the enamel on the front faces is thicker than that at the sides and back. Consequently it is not worn away so quickly, and the teeth thus become chisel-edged. Unlike the incisors of other animals, they retain their power of growth by means of persistent pulps. There are two other small incisors on the upper jaw behind the large ones (Fig. 100). This second pair of incisors occurs only in the Rabbit and Hare.

There are no canine teeth, so that there is a long gap between incisors and premolars. Into this gap the fleshy, hairy lips project and thus, together with the tongue, help to draw food backwards into the mouth. They also make a barrier that prevents such substances as chips of wood from getting either into the œsophagus or the wind pipe.

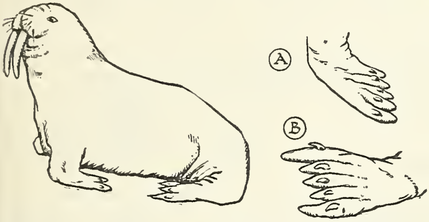


Fig. 99.—Walrus. A, Fore-limb. B, Hind-limb. Sketches made from museum specimen.

The pre-molars and molars have good grinding crowns for dealing with the vegetable food.

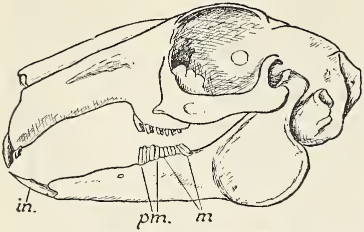


Fig. 100.—Skull of Rabbit to show dentition. *in.*, incisor; *m.*, molar; *pm.*, pre-molar.

Effective gnawing is further provided for by the articulation of the jaws; backward and forward, as well as upward and downward, movement is possible. By this means the herbage, when cropped, can be pressed against the inner surfaces of the upper incisors by the outer faces of the lower ones.

The persistent growth of the incisors has one disadvantage. Should one of these teeth get broken, or should the jaw be injured in such a way that the two incisors do not work normally against each other, then the unopposed tooth will continue its growth and may eventually pierce the other jaw, preventing the mouth from opening and the animal from reaching its food.

The dental formula of Rabbit and Hare is (Fig. 100):

$$2\left[\mathrm{I}\,\frac{2}{1}\quad \mathrm{C}\,\frac{0}{0}\quad \mathrm{PM}\,\frac{3}{2}\quad \mathrm{M}\,\frac{3}{3}\right]=28.$$

Other Rodents do not possess the second incisors on the upper jaw and have fewer pre-molars.

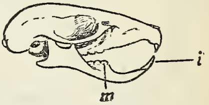


Fig. 101.—Skull of Mouse. *i.*, incisor; *m.*, molar.

The dental formula of the Mouse is (Fig. 101):

$$2\left[\mathrm{I}\,\frac{1}{1}\quad \mathrm{C}\,\frac{0}{0}\quad \mathrm{PM}\,\frac{0}{0}\quad \mathrm{M}\,\frac{3}{3}\right]=16.$$

The fore-feet of Rodents usually have five digits, whilst the hind-feet have four or five. The digits bear curved claws. The animals are either plantigrade or sub-plantigrade (Fig. 102). When a Rabbit is at rest the whole foot is placed on the ground; when leaping it becomes digitigrade.

7—Insectivora.

The Insectivora are generally small, furry, burrowing animals. Despite their name they are not entirely insectivorous. The animals of this order are probably rather primitive among mammals. They are not highly specialised. They have small brains, elongated muzzles or snouts, five clawed digits on each foot, and their progression is plantigrade.

Two interesting little animals are included in this order : the Mole and the Hedgehog.

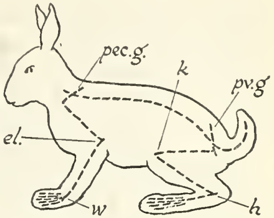


Fig. 102.—Rabbit. Outline showing position of limbs and skeleton in a sub-plantigrade animal. *el.*, elbow ; *h.*, heel ; *k.*, knee ; *pec.g.*, pectoral girdle ; *p.v.*, pelvic girdle ; *w.*, wrist.

The Mole.

The Mole is beautifully adapted for burrowing (Fig. 103). It has an almost cylindrical body, smooth soft fur, tiny eyes which are protected by the fur, no external ears, and hands whose palms turn outwards in order to scoop away the earth, which is then pushed aside with the help of the mobile snout. The hind-limbs are used chiefly for progression and are not specially modified for digging purposes. The Mole gets its food from the soil. This food consists of worms, insect larvæ, and such-like creatures : all the numerous soil population that the gardener comes across as he digs.

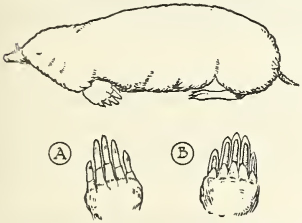


Fig. 103.—Mole. A, Back of hand. B, Palm of hand. Showing curving claws adapted for digging.

The Hedgehog.

The Hedgehog is also an exceptionally interesting little creature. It is one of the few mammals that hibernate. Having found for itself a convenient hole, it lines it with leaves. Within this shelter it proceeds to curl itself up into a ball, and here it sleeps throughout the winter. During this season its temperature falls very greatly. The curling up is brought about by the contraction of strong ventral muscles. Further protection is afforded by spines, which are modifications of hairs. They can be extended at right-angles to the body, or made to lie flat when they are not required.

8—Chiroptera.

The order Chiroptera (Greek *Cheir*, hand ; *pteron*, wing) consists of the Bats. Here is seen the only attempt made by any of the mammals to achieve aerial life. It is exceedingly interesting to compare parallel modifications in Birds and Bats.

Bats, like Birds, are very light ; they have somewhat rigid vertebræ and a high temperature. In both animals the lower side of the wing is concave. The formation of wings has, however, come about in Bats at a greater cost. Not only the fore-limbs, but the hind ones also, have been sacrificed for this purpose (Fig. 104). As a result the Bat can progress but poorly on land.

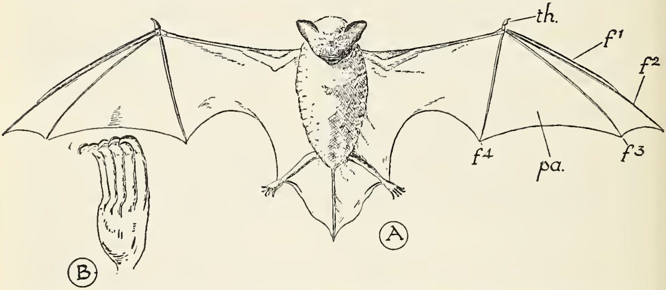


FIG. 104.—A, Bat. B, Foot in hanging position showing claws and equal toes. f^1., f^2., f^3., f^4., first, second, third, and fourth fingers ; *pa.*, patagium ; *th.*, thumb.

The wing is made up of a thin fold of skin, the *patagium*. This is stretched on a framework made up of the four extremely long digits of the fore-arm, rather as the silk of an umbrella cover is stretched over its wire. This thin skin extends from the sides of the body, completely enclosing the bones of arm and fore-arm and the four digits ; only the clawed thumb is left outside. It also covers the hind-limb, with the exception of the foot. Beyond the hind-limb it is continued to the tail. Even this is not all. Not only have the legs lost their free movement but, for better extension of the wing, they have become fixed in a position with the knee bent backward instead of forward, so that the little animal can, at best, only shuffle along. The chief use of the hind-limbs is to enable the Bat to hang, which it does, upside down, by means of the clawed digits (Fig. 104, B).

Food is caught on the wing at, or after, dusk. The Bat dislikes a strong light. Its sense of touch is extremely delicate. On the face are developed sensitive patches of skin which enable it to perceive faint disturbances in the air. A blind Bat will fly about a room across which threads have been stretched without even touching them. It is by means of this extremely sensitive sense of touch that the Bat is guided. Sense of hearing does not appear to be strong, notwithstanding the extremely large ears. The eyes are degenerate, but the expression "blind as a bat" is an exaggeration.

The Bat also hibernates, but not so thoroughly as the Hedgehog.

9—Primates.

Since Man himself is a member of the Primates, this order has naturally a very special interest. It includes also the Lemurs, the small Monkeys, and the large Apes. The Primates are, for the most part, arboreal, and this habit of life accounts, to some extent, for their characteristics. Unlike almost all other mammals, they have limbs that are wholly free from the general skin of the trunk; their movements are much freer, as a result of this.

Progression is plantigrade. The five digits of each limb have, in most cases, flat nails instead of claws. The big toe, except in the case of civilised Man, can be separated from the others and used for clasping. In most cases this is also true of the thumb.

The Lemur.

The simplest of the Primates is the Lemur (Latin, *lemuris*, a goblin). It is a little large-eyed animal of nocturnal habits, living in the trees of the forests of India, Africa, the Malay Archipelago, and Madagascar. It is a member of a very ancient race. Fossil forms occur in the very earliest strata of the Eocene period. It is probable that this little animal is the nearest living representative of the line from which Man has descended.

In arboreal life a high degree of evolution is likely to be achieved. Greater intelligence is required than in life on land, and the senses are likely to become more acute.

Arboreal Life.

The arboreal animal does not depend much upon sense of smell, and this is not so highly developed as in land mammals. But it does require keen sight and accurate co-ordination of movement, if it is not to suffer from falling from the tree. Most important of all, as a factor making for progress, is the emancipation of the fore-limbs. Freed from the duties of support and progress, they are able, by means of their opposable hands, to examine, by feeling and handling, the objects with which they come in contact.

Of the Monkey tribe, the large tailless Apes are nearest to Man. They never go completely on all fours, but their arms are longer than their legs. Only the Gibbon has learned to walk erect, and this only with the help of his immensely long arms, which actually reach the ground.

Apes and Monkeys.

The chief morphological characteristics which mark Man off from the rest of the mammals are his very large and convoluted brain and his upright gait.

Man.

The brain of the average Man weighs 48 or 49 ounces. That of the Gorilla never exceeds 20 ounces.

Man has assumed the upright attitude completely. His weight is supported by, and his progression depends on, the hind-limbs only. The inverted S-shaped curve of the vertebral column is adapted to the upright position. It should be noted, however, that it is only by muscular action, controlled by the nervous system, that a Man keeps the upright position. A baby has to be taught to stand and to walk. We all fall over on our faces when we faint.

Man is less hairy than the majority of Mammals.

The dentition of Man is similar to that of the higher Apes:

$$2\left[\mathrm{I}\,\frac{2}{2}\quad \mathrm{C}\,\frac{1}{1}\quad \mathrm{PM}\,\frac{2}{2}\quad \mathrm{M}\,\frac{3}{3}\right]=32.$$

The dentition is unique in that the canines are little bigger than the incisors, and there is no gap between canines and incisors.

Other characteristics peculiar to Man are the possession of a chin, foreshadowed in some of the higher Apes ; and of a nose which is produced by the prolongation of the nasal bones of the skull. His arms are short. His toes are not opposable, since his hind-limbs are used entirely for progression and support.

PRACTICAL WORK

Wherever possible the external characters and modes of progression should be studied in the living animals ; Dog, Cat, Rabbit, and Mouse are usually available ; other types can be seen in zoological gardens.

Dentition must be studied from prepared specimens of skulls ; those of the Horse, Dog, Cat, Sheep, Rabbit, and Mouse are good types.

For a detailed examination of the feet of hoofed animals, feet of various kinds—Pig, Sheep, Ox—can always be obtained from a butcher.

In connection with this section it is essential that visits should be paid to a museum, where all the animals described can be studied and sketched.

SECTION III

THE GENERAL MORPHOLOGY AND PHYSIOLOGY OF THE MAMMAL

In Hydra the alimentary tract and the body-cavity are one and the same. In the Earthworm, as the result of the development of more complicated tissues and organs, it is not possible for food, taken in at the mouth, to reach all parts of the body in the simple manner that is entirely satisfactory in Hydra.

In the Earthworm earth is drawn in through the mouth by pharyngeal action and travels by peristalsis down the alimentary canal. This is a perfectly straight tube, just as long as the body in which it lies. It is open at each end, and its openings coincide with the body-openings, so that a diagram may represent the structure as one smaller tube within a larger (p. 38). In the inner tube the food is acted upon by digestive juices and prepared for absorption. But the enclosure of the food in a separate tube makes some transport system necessary, so that it can be carried to the surrounding parts of the body. Hence the necessity for a blood-supply.

In the body-wall of the Earthworm there are two kinds of muscles. Longitudinal muscles contract and cause it to shorten and thicken. Circular muscles, by their contraction, cause it to elongate. A primitive nervous system controls muscular action.

In Fishes the alimentary system has lost the character of the straight tube in the anterior part of the body, where a single fold throws it into the form of an N. Although the hind-gut is straight to outward view, it is provided internally with a spirally arranged flap, which greatly increases its absorbing area.

In the Frog and the Bird the alimentary tube has elongated greatly. As it is fixed at both ends it is, of necessity, thrown into a series of loops.

In Fish and Frog and Bird the greater complexity of the limentary system is accompanied by corresponding development of the vascular system. The blood-vessels are differen-iated into arteries and veins and the flow of blood is controlled y a heart.

There is also great elaboration in the nervous system. These higher animals have a spinal cord enclosed in protecting vertebræ, and this cord expands, anteriorly, into a true brain that is protected by a skull.

It is in the Mammal that all the various tissue systems have reached the highest complexity.

CHAPTER XII

THE ALIMENTARY TRACT

THROUGHOUT the life of every individual there is constant expenditure of energy, which involves the chemical decomposition of the tissues of the body and of the substances that their cells contain. To balance the breaking-down there must be a compensating building-up. For this renewal, as well as for the growth of new tissues, food must be absorbed.

As the tissues of the body differ in character, the diet of every individual must ensure the absorption of substances whose elements are of value in building and re-building these tissues.

The Nature of the Food.

Foodstuffs fall into three classes according to their chemical composition.

Carbohydrates are made up of the three elements, Carbon, Hydrogen, and Oxygen. The Hydrogen and Oxygen are in the same proportion as in water. Thus :

$C_6H_{10}O_5$, i.e. $C_6(H_2O)5$ = Starch.
$C_6H_{12}O_6$, i.e. $C_6(H_2O)6$ = Grape Sugar.
$C_6H_{22}O_{11}$, i.e. $C_6(H_2O)11$ = Cane Sugar.

Fats are also made up of Carbon, Hydrogen, and Oxygen, but in different proportions. Fat meat, butter, and all oils are included in this class of foodstuffs.

Proteins contain Nitrogen in addition to Carbon, Hydrogen, and Oxygen. Common proteins are lean meat (myosin), the white of egg (albumin), the glutin of all cereal foods, and the casein of cheese.

The normal human diet includes these various foods. In the alimentary tract they are acted upon by secretions, commonly called digestive juices. During the process they undergo both chemical and physical changes and are brought into a suitable state for absorption by the blood. This is what is meant by *digestion*.

Digestion begins in the mouth in mammals and the teeth initiate the process.

In the human adult there are eight teeth on each side of the upper and lower jaw. The large front tooth is the incisor (I). Next to this is the canine, or eye-tooth (C). Farther back are the two smaller double teeth, the pre-molars (PM). Behind these are three molars, or large double teeth (M). The arrangement of the teeth can be set down graphically thus :

The Teeth.

$$2\left[\mathrm{I}\,\frac{2}{2}\qquad \mathrm{C}\,\frac{1}{1}\qquad \mathrm{PM}\,\frac{2}{2}\qquad \mathrm{M}\,\frac{3}{3}\right]=32.$$

Each tooth is firmly inserted in the bony socket of the jaw. This basal part of the tooth is composed of bone and is generally spoken of as *cement*. The part of the tooth that protrudes is made up of *dentine*, a substance that closely resembles bone. The dentine encloses a cavity containing nerves and blood-vessels. This is the *pulp-cavity* (Fig. 105). The whole of the protruding part of the tooth is covered with *enamel* which is extremely hard and therefore protective.

In the Rabbit there are twenty-eight teeth only, and its dental formula is :

$$2\left[\mathrm{I}\,\frac{2}{1}\qquad \mathrm{C}\,\frac{0}{0}\qquad \mathrm{PM}\,\frac{3}{2}\qquad \mathrm{M}\,\frac{3}{3}\right]=28\ (\text{p. }140).$$

While the teeth are tearing and grinding the food in the mouth it is being moistened and lubricated by saliva, which is produced by the salivary glands.

Saliva.

A *gland* is a mass of specialised cells that prepare and discharge some particular substance to carry out some special work.

In our mouths there are three pairs of salivary glands, responsible for providing its characteristic moisture. Of these the largest are the *parotid* glands. Opposite the pre-molars the tip of the tongue can find a little prominence on the cheek, and here is the glandular opening. The other two pairs are the *sublingual* and the *submaxillary*. Their names indicate their position, for both pairs open below the tongue, near the tongue-string. In the Rabbit a fourth pair, the *infra-orbital* glands, are situated just below the eye-balls.

Even before food has reached the mouth the salivary glands pour out their secretion. The mere sight of it has caused the flow. Therefore, quite literally, the mouth is watering.

When food is offered to a Dog he approaches licking his lips to get rid of this preliminary flow of saliva. If the food is withheld, the saliva may actually drip from the corners of his mouth.

The saliva not only moistens the food, making it easy to swallow, but it also helps to bring out the taste. There is much more pleasure in scrunching sweets than in letting them lie passive in the mouth, because the act of scrunching causes a more copious flow of saliva, and the taste is thereby intensified.

As already stated, the actual digestion of food begins in the mouth, and it is the saliva that brings about the preliminary change.

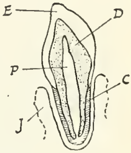


FIG. 105.—Tooth (diagrammatic). *C.*, cement; *D.*, dentine; *E.*, enamel; *J.*, jaw; *P.*, pulp cavity.

Enzymes.

Every change that takes place in food as it passes along the alimentary tract is due to bodies called *ferments* or *enzymes*. What these important bodies *do* is well known; as to what they actually *are* we are still in ignorance, for their chemical structure is unknown.

Each enzyme acts on one substance only, causing it to change chemically. The enzyme itself, apparently, undergoes no change; its action, therefore, is *catalytic*. This term is familiar to all who have prepared oxygen from potassium chlorate, when the oxygen is obtained more readily, and in greater quantity, by the admixture of manganese dioxide. At the end of the reaction this substance is unchanged both in character and amount.

Ptyalin.

The digestion that begins in the mouth is due to an enzyme present in the saliva. This is called *ptyalin*. Its particular chemical action is to turn starch into sugar by a process of hydrolysis, that is, by causing water to unite with the starch:

$$2\ C_6H_{10}O_5 + H_2O \rightarrow C_{12}H_{22}O_{11}$$
$$\text{starch} + \text{water} \rightarrow \text{malt sugar.}$$

In chewing bread the change can actually be detected if the swallowing process is delayed. A small lump of laundry starch, allowed to rest on the back of the tongue, also begins to taste sweet as a result of the action of ptyalin.

The Alimentary System.

In the back of the mouth, the *pharynx*, there are two openings. One of these is the *glottis*, and leads into the windpipe, or *trachea* (Fig. 112). The other leads into the *œsophagus*, the anterior part of the alimentary canal.

In the action of swallowing, the food must pass beyond the glottis before it can reach the opening to the œsophagus. The glottis, therefore, needs some protection against the entry of food. This is provided by the *epiglottis*, a triangular flap, strengthened with cartilage. At the time of swallowing, the epiglottis rises a little in front of the glottis. In this way it forms an obstruction to the stream of food, diverting it on its journey to the œsophagus. Even with this protection it sometimes happens that food "goes the wrong way": a crumb blocks the glottis and breathing is interfered with until the obstruction is displaced.

Peristalsis.

As soon as food leaves the mouth it enters the actual digestive tube. The first part of this tube, the œsophagus, connects the mouth with the stomach. Normally it lies flat and only becomes a circular tube when food passes along it. This passage of food is brought about by muscular action, known as *peristalsis*. Muscles are distributed in the wall of the œsophagus as in the body wall of the Earthworm. By their action a wave of dilatation and contraction passes along the tube, so that the food is pushed onwards. Pinching a piece of rubber tubing that encloses a pea, and drawing the finger and thumb along its length, gives a rough idea of the muscular action in the œsophagus.

Antiperistalsis.

As a result of change in nervous control, it happens sometimes that peristalsis takes place in the opposite direction. The food is then pushed upwards towards the mouth and the individual is sick.

In Sheep and Cattle antiperistalsis is the normal procedure. After a period of persistently cropping the grass the action of peristalsis is reversed and the animals then chew the cud (p. 132).

During the passage of the food along the œsophagus the digestive action of saliva is still continued. When, however, the food has been in the stomach for about an hour this particular action ceases.

The Stomach.

The *stomach* is a dilated part of the alimentary tract that lies across the body (Fig. 106). In its walls, too, muscles run both longitudinally and in circles ; but in addition there are others disposed obliquely among the circular muscles. Just as the body of the Earthworm is caused to contract and elongate by the alternate action of longitudinal and circular muscles, so do these movements take place in the stomach. At the same time the action of the oblique muscles causes it to rock slightly.

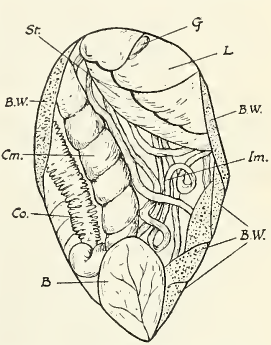


Fig. 106.—Abdomen of Rabbit. *B.*, bladder ; *B.W.*, body wall ; *Cm.*, cæcum ; *Co.*, colon ; *G.*, gall-bladder ; *Im.*, ileum (small intestine) ; *L.*, liver ; *St.*, stomach.

The result of these combined movements is that all the food the stomach holds is well covered by digestive or *gastric* juices, produced by glands in its wall. In the human stomach these secretions contain two enzymes, *pepsin* and *rennin*, and hydrochloric acid. The ability of dogs to digest bones depends upon the fact that the proportion of acid in their digestive juices is great, and it is this that acts upon the calcium phosphate of the bone. Because of the very acid character of the returned food a sick dog may destroy the colour of a carpet.

Food may remain in the stomach for some considerable time. As long as it is there the gastric juices flow. One effect of this flow is an interference with the action of ptyalin in changing starch into sugar. This change can only take place in an alkaline medium. It follows, then, that as hydrochloric acid reaches portions of swallowed food, this particular change is checked. The acid is instrumental, also, in keeping the stomach comparatively free from germs.

The action of pepsin is limited to proteins and only takes place in an acid medium. Thus the digestion of meat, eggs, cheese, fish, and other proteins begins in the stomach. In some illnesses of a digestive nature patients are recommended to take peptonised food ; that is, protein food already acted upon by pepsin extracted from the glands of some lower animal. Taking in such food, already partially digested, relieves the stomach of a certain part of its work.

Pepsin.

Rennin acts upon milk, causing it to curdle. This is a matter of common knowledge, for " rennet " is a commercial commodity, used in making junket. It is interesting to note that in the making of junket the milk must be warmed before the rennet is added. In the stomach, naturally, the curdling reaction is brought about at a temperature higher than that of the surrounding air.

Rennin.

When babies are sick it is the curdled milk from the stomach that is brought back to the mouth by the contraction wave of antiperistalsis.

Liquids other than milk pass through the stomach directly and unchanged. As milk contains a protein it is essential that it be partially digested before reaching the intestine. The curdling holds it back in the stomach until it has been acted upon by pepsin and brought into a suitable state for the next stage of the journey.

There is no digestion of starch in the stomach. Fats, also, are not digested here ; but these are at least changed physically, being liquefied by the higher temperature of the body. Why the stomach does not digest itself is a problem. Such *auto-digestion* may occur abnormally, as, for instance, when an apparently healthy person, in certain cases, dies suddenly after a meal ; or again when a patient suffers from a gastric ulcer. The protection against auto-digestion depends upon unimpaired circulation of the blood, possibly aided by the secretion of some protective enzyme.

Food enters the stomach at the cardiac end. As *chyme* it leaves for the small intestine at the pyloric end.

The small intestine is a very long, narrow tube, thrown into many loops. In Man it is about 20 feet in length. Even in the Rabbit it is usually 8 feet long.

The Small Intestine.

The first part of the small intestine curves somewhat abruptly, then follows a posterior course which, in the Rabbit, extends almost to the posterior end of the abdominal cavity; here it curves and passes directly forward.

In the U-shaped loop thus formed lies the *pancreas* (Fig. 107). It is the pancreas of sheep and oxen that is sold by butchers as sweetbread. The particular part of the small intestine that more or less encloses the pancreas is called the *duodenum*, because in Man it is, approximately, 12 inches long (Latin *duodeni*, 12 each).

The Duodenum.

The passage between stomach and duodenum is closed by a strong ring of circular muscles. The constriction that these muscles surround is called the *pylorus* (Greek *puloros*, a gate-keeper).

The pyloric muscle relaxes at intervals to let some portion of the partially digested food pass from stomach to duodenum. The control of this muscle is entirely independent of the will of the individual, whether that individual be Rabbit or Man. Such an involuntary muscle is called a *sphincter* muscle.

The reason for distinguishing the duodenum from the rest of the small intestine is that ducts open into it, both from the liver and from the pancreas, bringing secretions to carry the work of digestion a stage farther. It is estimated that, in Man, each pours about one pint of liquid daily into the duodenum to help in this digestive work.

It is evident, then, that both the liver and pancreas are glands: they are made up of specialised cells that prepare and discharge some particular substance to carry out some particular work. In this case the substances are discharged along ducts that open into the duodenum, and their special function is to bring the work of digestion towards its conclusion.

The pancreas is a very diffuse gland with many branches, all of which pour their secretion into one duct (Fig. 107). In the Rabbit this duct opens into the duodenum a little beyond the forward bend.

The Pancreas.

The pancreatic secretion contains three enzymes. Of these *diastase* attacks the starchy food in the duodenum, completing the conversion into sugar that was begun by the saliva. The action of *trypsin* is limited to proteins, that are now changed to peptones. In their passage along the small intestine the peptones are still further broken down into substances known as amino-acids. The third enzyme in the pancreatic juice is *lipase*. Its action is to emulsify fats and also to decompose them, with the formation of fatty acids and glycerine. The acids combine with certain alkaline salts that are present, forming soluble soaps.

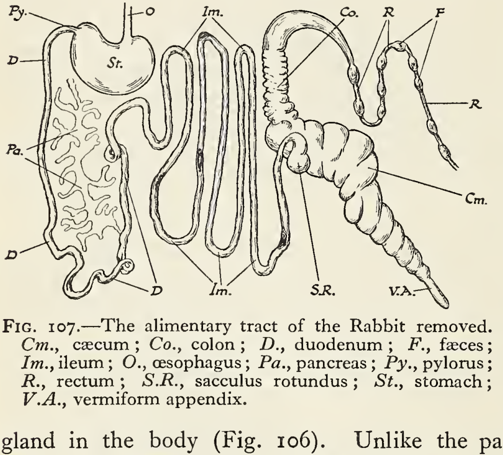


FIG. 107.—The alimentary tract of the Rabbit removed. *Cm.*, cæcum; *Co.*, colon; *D.*, duodenum; *F.*, fæces; *Im.*, ileum; *O.*, œsophagus; *Pa.*, pancreas; *Py.*, pylorus; *R.*, rectum; *S.R.*, sacculus rotundus; *St.*, stomach; *V.A.*, vermiform appendix.

The Liver.

The liver is much the largest gland in the body (Fig. 106). Unlike the pancreas, it is extremely compact. It consists of a large right and left lobe, each of which is incompletely divided into two. Near the dividing line of the two lobes, but actually embedded in that of the right side, is the *gall-bladder* (Fig. 106). The glandular cells of the liver secrete *bile* which, after passing through the gall-bladder, reaches the duodenum by way of the bile-duct. In the Rabbit the bile-duct enters the duodenum just a short distance beyond the pylorus. In Man bile-duct and pancreatic duct unite and enter the duodenum as a common duct, very near the pylorus.

The action of the bile upon the food in the duodenum is digestive. Its particular digestive function appears to be that of co-operating with the pancreatic juice in the digestion of fats.

The Villi.

Neither in the stomach nor in the intestine is the inner wall a plane, smooth surface. Its lining, or mucous membrane, is thrown into numbers of folds or ridges. In the stomach these get more or less straightened out when the stomach is full of food. In the intestine they are permanent; from the intestinal wall countless numbers of delicate, finger-like processes project into the interior of the tube. These are the *villi*. They give a plush-like appearance to the intestinal lining. Between the bases of the villi there are many small glands whose secretions finally complete the digestive process. The food, taken in at the mouth, is now, as a result of a long series of events, not only made soluble, but brought into a completely fit state for use in repairing wear and tear, and in providing a fundamental store, as it were, of potential energy for the individual's use.

As in the body wall of the Earthworm, so, too, in the wall of the small intestine of mammals, the muscles are arranged in longitudinal and circular bands. As in the œsophagus, the rhythmic contraction of these muscles causes peristaltic action, so that food does not clog any one portion of the tube.

Distribution of Digested Food.

The next necessity is the removal of the prepared food from the intestine and its distribution throughout the body. In each villus there are capillaries of arteries and veins; there is also a very delicate *lacteal* tube. These are, in great part, responsible for the absorption of the digested food.

Sugar is the one food that can enter the blood-stream directly and without change. This is the reason why a fagged feeling, during a long tramp, or after arduous exercise, is quickly dispelled by eating chocolate.

The soluble carbohydrates and amino-acids pass through the extremely thin walls of the vein capillaries in the villi. They are then conducted from the intestine to one of the main veins of the vascular system, which carries them to the liver (p. 194).

The fats reach the blood by a very circuitous route. They enter the lacteals of the villi and are, by them, carried away from the intestine to enter the *lymph circulation*. As *chyle* the fats pass into a large lacteal vessel which runs forward in the body to the neck. Here it opens into the left jugular vein, and the fats thus enter the blood-stream and are distributed (p. 185).

Secretin.

There is just one more function of the small intestine to note. As soon as partially digested food from the stomach enters the duodenum, the glands in the walls of the small intestine produce a substance called *secretin*. This at once enters the blood-capillaries of the villi and is carried by the blood to the pancreas. Here secretin gives the signal for the pancreas to produce its special enzymes. These pass along the duct and enter the duodenum, where they complete the digestion of that partially digested food whose entrance into the duodenum caused this whole circuit to be set in motion.

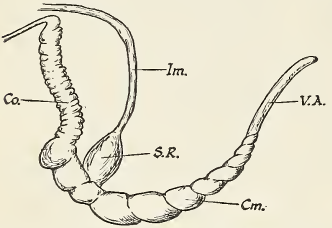


FIG. 108.—The junction of small and large intestine in the Rabbit. *Cm.*, cæcum; *Co.*, colon; *Im.*, ileum (small intestine); *S.R.*, sacculus rotundus; *V.A.*, vermiform appendix.

Excretion.

The small intestine, or *ileum*, enters the large intestine, or *colon*, at a right angle, in such a way that one part of the large intestine ends blindly (Fig. 108). This part is the *cæcum*, and terminates in the *vermiform appendix*, that may cause so much trouble in the human body, where its opening is extremely narrow. The trouble is caused by bits of hard food finding their way through this narrow opening into the appendix, where they set up inflammation.

In the Rabbit the appendix is apparently a functional part of the digestive tract and is particularly concerned with the digestion of cellulose. As the Rabbit is a vegetable feeder this makes up a large proportion of its diet.

So many digestive juices have been poured upon the food in its passage along the alimentary tract, that it is in a very liquid state. The work of the colon is to absorb, into the blood, a large proportion of the watery medium. As a result of this, the waste from the digestive processes becomes much more solid and suitable for expulsion from the *anus*, which, like the pyloric end of the stomach, is closed by an involuntary, or sphincter, muscle.

It is obvious that the long stretch of alimentary tract cannot just lie about anyhow in the body cavity, or *cœlom*. It is held in place by a delicate membrane, the *mesentery*. This keeps the different parts of the tract in their respective positions and also suspends the whole in the body cavity, because it is attached to the body-wall dorsally.

Mesentery.

The mesentery is disposed in two layers and is a continuation of the *peritoneum*. This is the thin, glistening tissue that lines the whole of the body cavity and is plainly seen in animals that have been cut ventrally and hang in the butchers' shops.

Peritoneum.

PRACTICAL WORK

1. Make a little *starch* paste in a test-tube and note the blue coloration of starch upon the addition of iodine.

2. Take 10 c.c. of a solution of lump *sugar* ; add a drop of dilute hydrochloric acid and boil for one or two minutes to turn the cane-sugar into grape-sugar. When this is cool, neutralise with sodium carbonate. Add Fehling's solution and boil again. Note the reddish colour that results. This s the proof of the presence of grape-sugar.

3. Put a little thin starch-paste into a test-tube and add aliva. Cork the tube and keep it in a moderately warm place. n the following lesson test a portion of the contents of the ube with iodine. There is no reaction, therefore starch is no longer present.

Test the remainder, as described above, for sugar. The eddish colour results, confirming its presence.

4. *Protein* test. Dissolve 1 c.c. of mercury in 20 c.c. of oncentrated nitric acid and add 40 volumes of water. This solution is known as Millon's reagent. If it is added to the lbumen of egg a white precipitate is formed, which turns

red on boiling. It is well to add a small pinch of salt to a little white of egg (about 2 c.c.), then shake this up well with 40 c.c. of water and filter before testing it with the reagent.

5. *Digestion of Protein.*—Put a piece of hard white of egg, or a very small piece of lean meat, into a test-tube with a little water. Make this very slightly acid with dilute hydrochloric and add a little pepsin, which any chemist will supply. The proteins are dissolved.

6. To show that pepsin acts only in an acid medium, repeat the former experiment, omitting the hydrochloric acid.

The Digestive Tract.—Examine a Rabbit that has been prepared to show the alimentary system and draw the parts as they lie.

For this purpose the Rabbit should be pinned, lying on its back, to a dissecting board. The skin should be cut ventrally by a median slit, extending the whole length of the body. To separate and turn back the skin neatly it is well to use the handle of a scalpel.

In the pectoral region a transverse cut on either side gives flaps, that help in pinning it firmly. The limbs are extended to their full length and fixed with a strong drawing-pin through each pad.

In this position the ventral body wall (the flesh) should be cut by a slit up the middle, as far as the diaphragm, which makes a delicate, vertical partition separating the abdomen from the chest or thorax.

Anterior transverse cuts give fuller exposure of the parts and again serve as flaps for pinning the animal more firmly to the board.

The delicate tissue surrounding all the abdominal parts is the mesentery. When the liver and the whole alimentary canal have been drawn *in situ*, the mesentery surrounding it, and connecting it with the dorsal wall, should be cut or torn away. Two cuts, one across the œsophagus and the other across the rectum (the end bit of the gut), make possible the removal of the whole alimentary tract, which can be arranged and drawn as shown in Fig. 107.

Note.—If the Rabbit is kept in a vessel containing 2½ per cent. formalin, it will be perfectly pleasant to use in lessons extending over a long period.

CHAPTER XIII

THE BLOOD-STREAM

The food that has been rendered soluble and suitable for absorption during its passage along the alimentary tract is distributed to every part of the body by the blood. To carry out the work of distribution it is obvious that the blood must be kept constantly moving. The movement is controlled by the motor mechanism of the heart, through which the blood passes twice on each journey round the body. It follows, therefore, that not only is the blood flowing *from* the heart in one direction, but that in another direction it is streaming *towards* the heart.

Arteries and Veins.

Blood is carried *away* from the heart by vessels known as *arteries*. When a human being is at rest the heart is forcing into the arteries about five pints of blood every minute. In running upstairs the volume is increased to something like thirty-five pints a minute. To resist this enormous pressure the walls of arteries must be very strong; but at the same time they must be elastic, so that their diameter may vary and allow them to expand, as the volume of blood they carry varies. To fulfil these conditions one layer of the arterial wall is made up of circular muscle fibres and firm elastic tissue.

The branches of the arteries are of smaller diameter than the main trunk. The succeeding branches are smaller still. Finally the ultimate branches may have a diameter of $\frac{1}{3000}$ part of an inch, and their walls are made up of only a single layer of cells. These ultimate branches are the *capillaries*.

The blood is carried *to* the heart by *veins*. They frequently run side by side with the arteries, for the general distribution of the two systems of blood-vessels in the body is the same. The structure of the veins, too, is on the same general plan as that of the arteries, but their walls are not nearly so elastic. Again, as in the arteries, so in the veins, the ultimate branches of the vessels are minute capillaries.

At first sight it is not apparent that blood is a tissue. It is, however, made up of numbers of living cells, embedded in a watery matrix. The liquid part of the blood, the *plasma*, is

The Blood.

practically colourless. It is really water, containing many substances in solution. Of these, certain salts and proteins are substances which are proper to the blood, being actual constituent parts of it. Others are the soluble and prepared foods in course of distribution, and waste products, too, that the blood is carrying to the kidneys to be discharged.

The Blood Corpuscles.

There are two very distinct classes of living cells in the blood, and these are commonly known as the red and the white corpuscles (Fig. 109). In one cubic millimetre of the blood of a man there are as many as 5,000,000 red corpuscles ; in that of a woman there are 4,500,000 ; while in the blood of a new-born baby there are 6,000,000 red corpuscles per cubic millimetre.

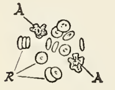


FIG. 109.—Blood corpuscles of Man. *A.*, amœboid (white) ; *R.*, red corpuscles.

When a hospital sends out an appeal for offers of blood-transfusion, the suitability of the blood of the volunteers must be tested, because the blood of different individuals may be antagonistic. The plasma of one individual, for instance, may make the red corpuscles of another give up their pigment, or hæmoglobin, which dissolves in the plasma. The red corpuscles are then utterly useless, as they have lost all power of carrying oxygen, and the patient dies.

Red corpuscles are formed by division of cells in the red marrow of bones. If the corpuscles have ever had a nucleus, it has disappeared by the time they enter the blood-stream. In shape they are rather like old-fashioned ju-jubes, being thin in the middle and thicker round the rim. They are thus bi-concave discs, but of extremely small diameter. Actually the diameter of a red corpuscle is just a little greater than the diameter of the capillary of an artery or vein. Under the microscope the individual corpuscles appear yellowish ; it is in the mass that they produce the characteristic red colour of the blood.

In a form that is not understood a very little iron is present in the red corpuscles, and it is because of the presence of iron that they are able to carry out their function, which is the carrying of oxygen from the lungs to all parts of the body.

The number of white corpuscles is much lower, the proportion of red corpuscles to white being approximately five hundred to one. They have a somewhat greater diameter than the red corpuscles ($\frac{1}{2300}$ inch). They are nucleated masses of protoplasm that move, as Amœba does, by means of pseudopodia. Their movement in the blood-stream is slow; and as, in the roadway, slow-moving traffic keeps near the kerb, so, in the blood, the amœboid corpuscles keep close to the walls of arteries and veins.

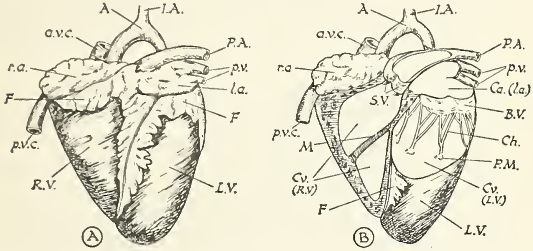


FIG. 110.—A, Sheep's heart (diagrammatic). B, The same: part of the walls of the ventricles and of the left auricle cut away. *a.v.c.*, anterior vena cava; *A.*, aortic arch; *B.V.*, bicuspid valve; *Ca.*, cavity of auricle; *Ch.*, chordæ tendineæ; *Cv.*, cavity of ventricle; *F.*, fat; *I.A.*, innominate artery; *l.a.*, left auricle; *L.V.*, left ventricle; *M.*, moderator band; *P.A.*, pulmonary artery; *P.M.*, papillary muscle; *p.v.*, pulmonary vein; *p.v.c.*, posterior vena cava; *r.a.*, right auricle; *R.V.*, right ventricle; *S.V.*, semi-lunar valves of pulmonary artery.

The Heart.

The heart of mammals lies in the thorax, between the lungs. It is conical in shape, the pointed end being directed posteriorly. It is made up of four chambers. Two of these are anterior and, because of a somewhat fanciful resemblance to ears, are called *auricles* (Latin *auris*, an ear). The posterior chambers are the *ventricles*. The left auricle opens into the left ventricle, and the right auricle into the right ventricle, but the left and right sides of the heart are most effectually separated one from another (Fig. 110).

All the blood that is brought *to* the heart enters by way of the auricles. All the blood that *leaves* the heart is expelled from the ventricles.

In the laboratory a Sheep's heart is generally used for investigation, partly because it is so easily obtainable, partly because its size makes it an easy object of study.

A groove on the ventral surface of the heart marks the division between right and left ventricle. This groove, which is filled with fat and appears as a white line, runs obliquely to the right, because the left ventricle forms the apex of the heart and has a greater length than the right ventricle. The ventricles, more particularly the left, have firm, muscular walls. The auricles, on the contrary, are flabby and puckered-looking.

In the Sheep's heart two large veins, the *venæ cavæ*, open into the right auricle, bringing to it, from all parts of the body, blood that has been deprived of oxygen (Fig. 110). From the auricle the deoxygenated blood passes into the ventricle. As soon as this is full it is abruptly shut off from the auricle by three triangular flaps, which project from the wall of the heart where auricle and ventricle meet. They hang down in the cavity of the ventricle until this is filled with blood. Then they float upwards, forming a roof to the ventricle and a floor to the auricle. The flaps, or valves, cannot be pushed upwards into the auricle, by pressure of blood in the ventricle, because they are attached to the wall of the ventricle by delicate fibres called the *chordæ tendineæ*, which themselves rest upon muscular papillæ (Fig. 110, B).

The blood is now at high pressure in the ventricle, whose wall contracts, exerting still greater pressure on the blood. As this is prevented by the closed valves from rushing back into the auricle, there is only one way by which it can escape ; this is by the *pulmonary artery*, which leads out of the anterior end of the ventricle and carries the blood to the lungs.

Circulation.

In the working of the body very little is left to chance. The contraction of the wall of the ventricle forces the blood into the pulmonary artery. It is then impossible for this flow to be reversed, or for the blood to return to the ventricle, because another series of valves guards the opening between ventricle and artery. These are the three *semi-lunar valves.* In shape they resemble the old-fashioned watch-pockets that formerly hung at the head of every four-poster bed. They are so placed that their semi-circular closed ends are to the ventricle, while their hollows face the cavity of the artery. When blood is passing into the artery they lie flat against its wall. When the contraction of the ventricle ceases, and pressure is reduced in the ventricle, the blood surges back along the pulmonary artery, but, in so doing, it fills the pockets of the semi-lunar valves and stretches them across the passage-way. Strengthened outgrowths from the edge of each pocket meet centrally, and the gap is completely closed.

The pulmonary artery then carries its blood directly to the lungs. In the lung-tissue it breaks up into capillaries. Through the thin walls of the capillaries the blood discharges into the lungs carbon dioxide that it has collected from all parts of the body.

These capillaries meet others that carry the blood that has become charged with oxygen from the air in the lungs. The latter unite to form the *pulmonary vein*, which carries the oxygenated blood to the left auricle of the heart. From the left auricle the blood drips through into the left ventricle. When the cavity of the left ventricle is filled (which coincides with the time of full pressure in the right ventricle) there is another abrupt closing of valves to shut off auricle from ventricle (Fig. 110, B). On this side there are only two valves, called the *bicuspid* or *mitral*, from a fancied resemblance to a bishop's mitre. Those of the right side, being three in number, are called the *tricuspid* valves.

It is the work of the left ventricle to drive the oxygenated blood into an arterial system that carries it to all parts of the body. In this heavy work is found the explanation of the extremely muscular nature of the left ventricle wall. By the contraction of the ventricle, blood is forced along the *aorta*, a large artery, with extremely elastic walls, that leaves the heart at the anterior end of the left ventricle (Fig. 110). Here, too, the opening between artery and ventricle is guarded by three semilunar valves to prevent a backward flow of blood to the heart.

The Beat of the Heart.

The sounds of the heart's beat are probably due, in some measure, to the click of the closing valves. They are generally represented by the syllables lūbb-dŭp—lūbb-dŭp. Lūbb is the long sound that occurs when both ventricles simultaneously begin to contract. This is the *systole*. Dŭp marks the end of the contraction, and the closing of the semilunar valves. "——" is the silence period between two beats and marks the easy flow of blood into the heart when it is relaxed. This is the *diastole*.

Between the heart-beats, in the rest-period, there is still an even flow of blood in the vessels. Obviously, then, as the circulation is not jerky, it does not depend entirely upon the beating of the heart, but is, to some extent, controlled by the vessels themselves.

The Pulse.

There is a slight difference in the diameter of the red corpuscles of the blood and the capillaries through which they travel. In the capillaries, therefore, the red corpuscles must double up somewhat in order to pass along. Thus, to a certain extent, they plug the capillary tubes and set up a frictional resistance. This means that more blood is entering the aorta and the pulmonary artery from the heart than can pass from their branches into the capillaries. Because of this the main arteries are always distended with blood, which is pressing on the arterial walls. As each fresh volume of blood enters the arteries from the heart, the elastic arterial walls stretch to accommodate the extra flow.

In the silence period between two heart-beats the pressure of the blood on the arterial wall lessens, and the elasticity of the wall allows it to recoil. The alternate recoil and recovery of the wall forces the blood onwards, against the opposition set up in the capillaries. As the distension and recoil of the arterial wall occurs with every heart-beat, a wave of pressure travels along the arteries. It is this wave of pressure that is the *pulse*, readily detected in arteries that are near the surface, as at the temple and the wrist.

It is because of the presence of circular muscle-fibres in arterial walls, and because of the elasticity of the walls, that the arteries are able to regulate the supply of blood to different parts of the body. When blood is not required in any particular part, the cavity of the artery contracts, preventing the full flow of the blood-stream in that one direction. During the process of digestion, for instance, the full supply of blood is cut off from organs other than digestive. The brain is receiving less. A headache is often relieved, at least temporarily, by eating, because the blood, as it is said, is " drawn from the head."

Arterial Control.

If the brain is deprived of oxygen by receiving too little blood, *fainting* may follow. Here is the explanation of fainting as the result of long standing. The lower part of the body, the legs and feet, have been supplied with blood at the expense of the head. The brain is extremely sensitive to the oxygen supply, and it is because the supply is diminished, in such a case, that consciousness is temporarily lost.

Fainting.

In the case of a too-hot bath the arteries help the body to get rid of the excessive heat by an expansion of their cavities, due to muscular relaxation. That a greater volume of blood flows along the vessels is evidenced by the redness of the skin. Heat is given off, from the blood, through the skin. Accompanying this increase in superficial flow there is a restriction of the blood supply to the head. Therefore the normal oxygen supply to the brain is reduced and fainting may follow.

In the veins control of the direction of blood-flow is provided by pocket-like valves which are much like the semilunar valves that guard the entrance to the arteries. In veins they occur at intervals along the walls. A backward flow of blood at once fills the pockets, and by their distension the valves close the lumen of the vein until positive pressure is restored.

Control in the Veins.

The blood that passes through the chambers of the heart does not supply the muscles of the heart itself. For its nutrition, for its supply of oxygen, and for the removal of waste substances, the heart depends upon its own particular vessels. These are the coronary veins which enter the vena cava ; and the coronary arteries which are given off from the aorta, quite near its semilunar valves.

The Heart's Blood Supply.

PRACTICAL WORK

Prick the finger with a needle sterilised in the flame of a spirit-lamp. Let the blood drop on to a clean cover-slip. Put this on a clean slide, using just a little pressure, so that the blood spreads between slide and slip. Examine it under low and high powers of the microscope.

Without injuring the diaphragm cut through the ribs of the Rabbit and remove the wall of the thorax (chest).

The soft body anterior to the heart, possibly overlying it, is the *thymus gland*.

The heart is enclosed in delicate connective tissue, the *pericardium*. This must be cut away. Do not remove or injure the heart itself; it is needed later in following the course of veins and arteries.

The lungs are two soft, pinkish bodies, lying one on each side of the thorax, whose cavity they almost fill. They become deflated when the thorax is opened.

For detailed examination of a heart, the large heart of a Sheep is excellent, and any butcher will supply this. Make out the openings of the two caval veins into the right auricle, and of the pulmonary vein into the left auricle. Here the two anterior cavals meet and enter as one. In the Rabbit the three cavals enter separately. Push the handle of a dissecting needle or seeker down the veins, and see that this handle really does enter an auricle.

Similarly find the opening of the pulmonary artery at the anterior end of the right ventricle and of the aorta at the anterior end of the left ventricle. Push in the handle of the seeker and note that this time it goes right down into the ventricles.

Push the little finger into one of the veins, then into one of the arteries. Notice how strongly the latter grip the finger because of the elasticity of their muscular walls.

Dissection of the Heart.—Cut away part of the right auricle, just leaving its base as a cup-like rim. Let water drip into this from the tap and observe the rise of the tricuspid valves to close the aperture between auricle and ventricle. A slight squeezing of the ventricle makes this still more obvious.

With a scalpel cut the right ventricle wall, on the right, straight down to the apex. Then turn, cutting just to the left of the groove between the two ventricles.

Lift up the triangular piece of the ventricle wall thus produced and note within the cavity :

1. The columnar arrangement of the muscles of the wall.
2. The moderator band stretching across the cavity (not present in Rabbit or Man).
3. The flaps of the tricuspid valve.
4. The chordæ tendineæ, like the guy ropes of a tent.
5. The roundish papillary muscles which not only connect the cords with the wall of the ventricle but, by contraction and relaxation, control their working.

Cut a little way along the pulmonary artery, from the ventricle, and see the three semilunar valves.

CHAPTER XIV

RESPIRATION AND THE VASCULAR SYSTEM

Energy. THERE is no better description of the difference between *Potential* and *Kinetic Energy*, and the conversion of one into the other, than the much used illustration of a great reservoir at rest, whose still water holds enormous latent forces; and the same body of water after it has burst its dykes, so that the potential forces have become actual, and the vast flood of water, in its onward rush, sweeps away all obstructions from its path. The potential energy of the water has been converted into kinetic energy.

Every activity of the body, no matter how slight this may be, depends upon the change of potential into kinetic energy.

Metabolism. Accumulation of stores of potential energy in the body results from the building up of complex substances and the incorporation of organic compounds into the protoplasm. This building-up process is *anabolism.*

The energy the organism needs is almost entirely derived from the oxidation or combustion of the substances of the body, causing the breaking down of complex compounds, with the formation of simpler ones. This is a process of *katabolism* and involves a release of kinetic energy. *Metabolism* includes these two processes.

Oxidation, naturally, cannot take place without oxygen, and part of the process of respiration is concerned with the taking in of oxygen. Simultaneously carbon dioxide, resulting from the decomposition processes, is given out.

The Nose. The mammal obtains its necessary supply of oxygen from the air. In its passage from the outside world to the lungs the air travels by way of the nostrils, pharynx, larynx, trachea, and bronchial tubes (Fig. 111). In each nostril there are three scroll-bones, excellently seen in a section of a dog's skull. In life a moist tissue that secretes mucilage covers the scroll-bones, following every turn they make. This tissue contains very many blood-capillaries, as is seen by the readiness with which the nose bleeds.

As the air passes up the nostrils it is moistened by the mucous secretion and its temperature is raised, so that when it reaches the lungs it neither dries nor chills these delicate tissues. At the same time, as is evidenced by the state of one's handkerchief on a foggy day, the nostrils filter from the air a great deal of its dust and dirt. In this purifying of the air the hairs of the nostrils help greatly.

In the upper turns of the tissue that covers the scroll-bones, the olfactory cells are dispersed. These detect odoriferous particles in the air that passes over them, and therefore offer a protection against the inhalation of impure air.

The Pharynx.

The moistened, warmed, and purified air escapes from the nostrils to the back of the mouth, the *pharynx*, through the internal openings of the nose. Had the air been taken in directly from without, by the mouth, it would not have been made ready for its entry into the lungs. It is for this reason that breathing through the mouth is bad.

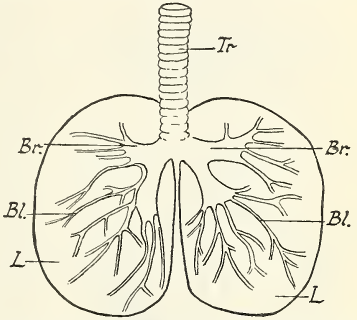


Fig. 111.—Diagram of human lungs. *Br.*, bronchus; *Bl.*, bronchiole; *L.*, lung; *Tr.*, trachea.

Air leaves the pharynx through the *glottis*, which leads into the organ of voice, the *larynx*, and this is connected with the

The Trachea.

lungs by a long, straight tube, the *trachea*, or windpipe (Fig. 111).

It is a simple matter to obtain from the butcher a mass of uninjured offal, comprising heart, lungs, windpipe, and œsophagus and to make out the structure of the various parts.

The trachea is strengthened by incomplete rings of cartilage, the gaps in the rings being dorsal. The reason for the dorsal incompleteness is plain. The œsophagus runs parallel to the trachea, and when it is distended, in the act of swallowing, its wall meets the wall of the trachea. The absence of cartilage in this region of the windpipe prevents frictional rub. The trachea branches into two *bronchi*. Some of the still smaller branches, the *bronchioles*, can be traced by cutting the alveolar tissue of the lungs.

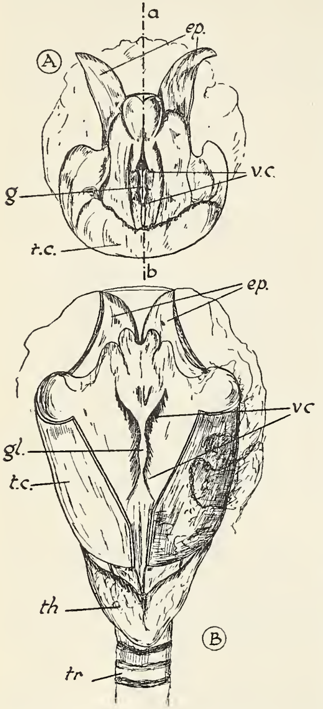


FIG. 112.—Larynx of Ox. A, As seen from above. B, Cut in the plane *ab* of A. *ep.*, epiglottis; *g.*, glottis; *gl.*, glottal slit; *t.c.*, thyroid cartilage (Adam's apple); *V.C.*, vocal chords; *th.*, thyroid gland; *tr.*, trachea.

The Larynx. The *larynx*, the chamber that leads from the pharynx into the trachea, is bounded by cartilaginous walls. The most obvious of these is the thyroid cartilage, which is very smooth and white and sculptured-looking. It encloses the larynx on the front and sides, but, like the rings of the actual trachea, it is incomplete dorsally. The thyroid cartilage in the human race is much more prominent in man than in woman, and is popularly known as "Adam's Apple" (Fig. 112, B).

The Vocal Chords. A cut through the windpipe is necessary to disclose the vocal chords (Fig. 112). These are two strips of tissue stretching across the larynx, supported by the cartilaginous walls, one on either side of the glottal slit. Air passing over them causes vibrations in the so-called "chords" and produces sound. The sound is produced as in the vibration of a blade of grass held between the thumbs of the folded hands and blown, or as in the reed-vibration of an organ-pipe. But, whereas the organ-pipe produces one note only, the vibration of the laryngeal " reed " produces an amazing range of sound. To outward appearance the laryngeal apparatus is the same in all human beings. It is extraordinary, therefore, that in the whole human race there are probably no two voices exactly alike.

When the throat is " hoarse " or when the voice is " lost," inflammation has restricted the gap between the chords and vibration is disturbed.

In adult man the vocal chords are longer than in a woman or in a boy. The change from the condition found in the boy to that of man is sudden, and the " breaking " of a boy's voice at this period is due to a failure in adjustment to the new conditions, and to lack of nervous control.

The " cracking " of the voice in old age is caused by loss of flexibility in the cartilages. A degenerative process has set in, in this most delicate organ, and vibration is reduced.

The trachea and bronchi are lined with a mucus-secreting membrane to trap dust that may enter. In addition, the cells of the membrane are provided with cilia, much like those of Chlamydomonas. These lash rhythmically, with a sharp stroke towards the glottis, the result being that the mucus, with its entangled dust, is swept into the mouth as phlegm.

The *lungs* are soft, spongy bodies lying freely in the cavity of the thorax, only held in position by the *bronchi*, and by the blood-vessels that enter them.

The Lungs.

The lung, for the most part, is a mass of minute air-sacs. This is very evident in boiling lights, which are lungs, for as the air in the sacs expands with heat, the lights rise so much in the saucepan that they must constantly be pressed down.

The *bronchioles* carry air directly into the air-sacs, or *alveoli*, and it is in them that the exchange of gases takes place. The alveoli have extremely thin walls and are very near together. Between the walls of the alveoli are networks of capillaries, so that the least possible width of tissue separates blood and air. If the alveoli of human lungs were spread out to form a flat sheet, this would cover an area of 100 square metres. This gives some idea of the great volume of air they are capable of holding.

The Mechanism of Breathing.

In the actual breathing process the cavity of the thorax is enlarged involuntarily; partly by the raising of the ribs, a movement that depends upon the strong muscles that lie between them; partly it expands because of the flattening of the *diaphragm*, the arched muscular partition that separates the thorax from the abdomen.

It is not the filling of the lungs with air that causes the thoracic cavity to expand. It is, on the other hand, the expansion of the thoracic cavity that causes air to be inhaled. To plagiarise a well-known line: "We breathe because we must and not because we will."

The elasticity of the lungs is partly responsible for the ejection of air, but expiration is also helped by the return of ribs and diaphragm to their original positions.

The air that has been drawn into the lungs fills the alveoli. Through the extremely delicate alveolar and capillary walls, the red corpuscles of the blood have the power of extracting oxygen from the alveolar air. The ease with which they take up the extra charge of oxygen depends upon a pigment they carry, called *hæmoglobin*. This forms, with oxygen, a very unstable compound, called *oxyhæmoglobin*, that is brilliantly red. The blood escaping from a cut owes its vivid colour to the oxygen it is extracting from the air as it drips. The value of hæmoglobin as an oxygen-carrier apparently depends upon a small proportion of iron which enters into its composition.

The capillaries, that have collected oxygen from the alveoli of the lungs, unite and finally form the pulmonary vein which carries the oxygenated blood to the heart. The blood enters the heart by way of the left auricle and, after passing to the ventricle, leaves the heart by way of the great aortic artery. It is now the business of the arterial system to carry oxygenated blood to every part of the body.

The Arterial System.

There is, in mammals, a good deal of variation in the arrangement of the chief vessels. The vascular system of the Rabbit is the best to choose for description, because the arrangement of its arteries and veins is readily demonstrated in the laboratory.

When the aorta leaves the left ventricle, it follows a very short forward course, then bends backwards, forming the *aortic arch*, which passes backwards, as the *dorsal aorta*, through thorax and abdomen, to the hinder part of the body (Fig. 113). As it passes through the thorax it gives off small, paired, *intercostal* arteries, which supply the ribs.

In the abdomen blood is carried to the stomach, the liver, and the spleen by a single large artery, the *cœliac*. A little way behind this a single artery, the *anterior mesenteric*, branches off from the dorsal aorta to supply the intestine and the pancreas. The dorsal aorta passes between the kidneys and gives off a *renal* artery to each. Still farther back paired *genital* arteries supply the reproductive organs, whether they be testes or ovaries. Just a little in front of the genital arteries an unpaired branch, the *posterior mesenteric*, is given off from the aorta to supply the back part of the alimentary tract. Behind them small *lumbar arteries* carry blood to the walls of the abdomen (Fig. 113).

The dorsal aorta now ends abruptly as a main vessel. It bifurcates, and its branches are the *iliac* arteries that supply the hind-limbs.

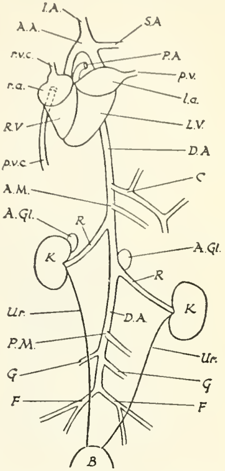


FIG. 113.—The chief posterior arteries (Rabbit). *A.A.*, aortic arch; *A.Gl.*, adrenal gland; *A.M.*, anterior mesenteric; *B.*, bladder; *C.*, cœliac; *D.A.*, dorsal aorta; *F.*, femoral (or iliac); *G.*, genital; *I.A.*, innominate; *K.*, kidney; *l.a.*, left auricle; *L.V.*, left ventricle; *P.A.*, pulmonary artery; *P.M.*, posterior mesenteric; *p.v.*, pulmonary vein; *p.v.c.*, posterior vena cava; *R.*, renal; *r.a.*, right auricle; *R.V.*, right ventricle; *r.v.c.*, right anterior vena cava; *S.A.*, subclavian artery; *Ur.*, ureter.

Blood is carried to the head and face by forwardly directed arterial branches that come off from the aortic arch (Fig. 114). From the curve of the arch the *innominate* artery arises. Almost immediately it branches, forming the *right carotid* and the *right subclavian* arteries. The *left* *subclavian* arises from the left side of the aortic arch. The origin of the *left carotid* is between this and the innominate. The carotids supply the head and face of the animal. The subclavians run laterally to supply the arms. Small branches from the subclavians pass to the chest and mammary glands, while a larger, *vertebral* artery passes through the vertebrarterial canals on each side of the vertebræ of the neck and so enters the skull (p. 205).

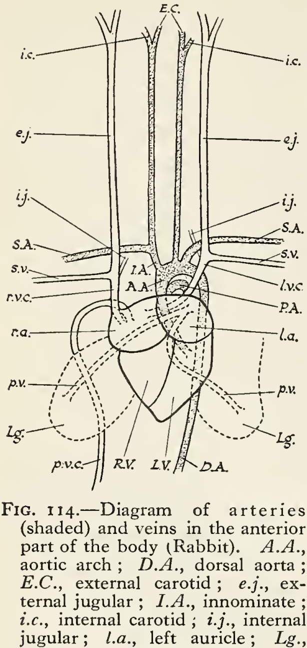


FIG. 114.—Diagram of arteries (shaded) and veins in the anterior part of the body (Rabbit). *A.A.*, aortic arch; *D.A.*, dorsal aorta; *E.C.*, external carotid; *e.j.*, external jugular; *I.A.*, innominate; *i.c.*, internal carotid; *i.j.*, internal jugular; *l.a.*, left auricle; *Lg.*, lung; *L.V.*, left ventricle; *l.v.c.*, left anterior vena cava; *P.A.*, pulmonary artery; *p.v.*, pulmonary vein; *p.v.c.*, posterior vena cava; *r.a.*, right auricle; *R.V.*, right ventricle; *r.v.c.*, right anterior vena cava; *S.A.*, subclavian artery; *s.v.*, subclavian vein.

All the arteries of this system are carrying oxygenated blood from the heart to the different parts of the body. In every tissue they supply, in the stomach, in the liver, in the pancreas, in the brain, for instance, they branch ever more and more, and finally terminate in capillaries.

The oxyhæmoglobin carried by the blood is unstable and readily parts with its oxygen in the absence of air. The tissues in which the capillaries lie are in this condition of air-poverty, and through the thin capillary walls the oxygen of the oxyhæmoglobin passes, to appease their oxygen-hunger.

The blood, now deprived of oxygen, must pass back to the lungs, through the heart, to pick up a fresh supply. This return journey is accomplished by way of the veins.

The Venous System.

In the various tissues served, as in the stomach, liver, pancreas, and brain, the capillaries of the arteries meet capillaries of the veins. It is, however, more than a mere meeting, for there is open communication between the two sets of capillaries, so that a complete network results.

The blood deprived of oxygen passes along the capillaries of the veins, which, at the same time, are collecting the waste carbon dioxide from the tissues. The capillaries unite to form larger veins in which the blood flows gently, carrying not only the " blue," or deoxygenated, blood to the heart and thence to the lungs, but also the carbon dioxide that the various tissues have produced. The greater part of the carbon dioxide has entered into combination to form sodium bicarbonate, which dissolves in, and is carried by, the plasma of the blood.

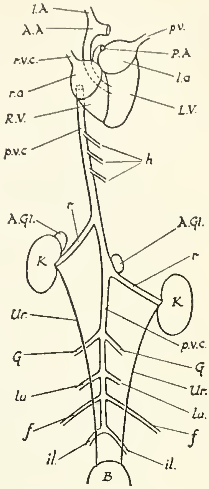


FIG. 115.—The chief posterior veins (Rabbit). *A.A.*, aortic arch; *A.Gl.*, adrenal gland; *B.*, bladder; *f.*, femoral (external iliac); *g.*, genital; *h.*, hepatic; *I.A.*, innominate artery; *il.*, internal iliac; *K.*, kidney; *lu.*, ilio-lumbar; *l.a.*, left auricle; *L.V.*, left ventricle; *P.A.*, pulmonary artery; *p.v.*, pulmonary vein; *p.v.c.*, posterior (inferior) vena cava; *r.*, renal; *r.a.*, right auricle; *R.V.*, right ventricle; *r.v.c.*, right anterior (superior) vena cava; *Ur.*, ureter.

In the hinder part of the body the *iliac* veins collect the blood from the pelvic girdle and thighs and unite to form the *inferior vena cava*, or *posterior vena cava*, or *postcaval vein.* It bears these three names (Fig. 115). In its forward course this vein receives blood from the *lumbar* region, the *genital* and the *renal* organs. More anteriorly *hepatic* veins bring to it blood from the liver, and *intercostal* veins bring blood from the region of the ribs.

The postcaval vein opens into the right auricle, and thus the blood from the hinder part of the body, deprived of oxygen and charged with carbon dioxide, is returned to the heart.

From the head, face, neck, and arms, blood is carried by *facial*, *jugular*, and *subclavian* veins, all of which form, by their union, on one side the *left precaval*, on the other the *right precaval* (Fig. 114). These, like the postcaval vein, lead the blood deprived of oxygen and charged with carbon dioxide to the right auricle of the heart. In the Sheep the two precaval veins unite before their entry into the auricle.

From the right auricle the blood passes to the right ventricle. From the right ventricle the pulmonary artery carries the deoxygenated blood to the lungs, where it gives up its charge of carbon dioxide to the alveoli.

The cycle of respiration is now complete. From the air in the lungs oxygen has been distributed to every part of the body. Carbon dioxide has been collected from the tissues and carried to the lungs for expiration.

The nature of the blood carried by the pulmonary artery and the pulmonary vein makes it clear that an artery and a vein cannot be defined in terms of the nature of the blood they carry. Whereas, generally speaking, an artery carries oxygenated blood, and a vein deoxygenated blood, in the case of the pulmonaries it is the other way round. The pulmonary artery is carrying blood deprived of oxygen. In the pulmonary vein the blood is heavily charged with oxygen. The only possible definition, then, is one that indicates the direction of the blood-flow: an artery carries blood *from* the heart, while a vein carries blood *to* it.

The Hepatic Portal System.

The entry of digested food into the main blood-stream is not direct, but is regulated by the liver. For this reason food is carried from the digestive tract to the liver by the *hepatic-portal system*. A *portal system* of veins is one which terminates in capillaries at both ends. In the hepatic-portal system one series of capillaries is in the intestinal region, the other is in the liver.

Digested food, with the exception of the fats, is absorbed by the capillaries of the villi of the intestinal wall. These capillaries unite, outside the intestine, to form the single, large portal vein. This carries the blood and the food it contains to the liver. Here it is distributed by the capillaries of the portal system, in readiness for its subsequent removal according to a regulated and well-ordered plan (p. 194).

After passing through the liver, the food enters the general blood-stream by way of the hepatic vein, then travels round the body to the various organs, which take from it the nourishment they need.

The capillaries of the villi in which the fats collect also pass, outside the intestine, into one main duct. This is the thoracic duct which goes forward to the neck, where it opens into the left jugular vein. In a dissection of the Rabbit the thoracic duct is very difficult to demonstrate. As its contents are colourless, it is not obvious like the veins and arteries, and its walls are so thin that they are generally torn in the preliminary processes of dissection.

PRACTICAL WORK

1. As the thoracic cavity of the Rabbit has been exposed, it is ready for the study of the veins and arteries.

The course of the veins should be followed first, because they are ventral to the arteries.

It is well to begin at the auricles and trace the veins backwards. The muscle (flesh) should be removed when necessary by very careful cuts with the scalpel, or by picking away with forceps. The walls of veins are easily injured.

The aortic arch, curving to the left, is very obvious and makes a good starting-point for tracing back the arteries.

Arteries have strong, resistant walls. They are paler in colour than the veins, because the heart's action has ceased, causing recoil of the arterial wall and expulsion of most of the blood into the veins. Often just a thin reddish streak is seen in the middle of each artery.

2. In the bunch of offal the trachea is seen branching into the two bronchi that support the lungs.

Epiglottis, larynx, thyroid cartilage, the bases of the thyroid glands, the thymus gland, can all be seen and drawn.

When the trachea is cut ventrally and the sides pressed apart, the two vocal chords are plainly visible.

CHAPTER XV

OTHER FUNCTIONS OF THE BLOOD

THE work of the red corpuscles is apparently restricted to carrying oxygen. As they have lost their nuclei they are not, strictly speaking, cells.

The white corpuscles are nucleated and play many parts.

The proportion of red corpuscles to white varies, but there are, in man, about five hundred red corpuscles to one white.

The largest *leucocytes*, or white corpuscles, are the *phagocytes* of the blood. Like Amœba they are able to put out pseudopodia, and they can ingest particles suspended in the blood-plasma. Thus they form a protecting army against bacterial invasion.

Phagocytes.

They are also able to make their way through the walls of capillaries, leaving these uninjured. After their escape through the walls they wander away in the body, often acting as scavengers and removing waste.

Very frequently their migration is a protective measure. It always occurs when micro-organisms, popularly known as germs, enter the body and multiply at any one spot. When a pricked finger swells, the inflammation is caused by the migration to the injured area of numbers of white corpuscles. They ingest the bacteria that are rapidly multiplying in the festering wound, and the matter, or *pus*, that accumulates contains the white corpuscles and the micro-organisms that they have engulfed.

Other, and smaller, white corpuscles are incapable of *phagocytosis*, that is, of putting out pseudopodia and ingesting foreign bodies. It is difficult to say exactly what their mode of action is, but it seems probable that they, also, defend the body against bacterial attack, but that the nature of the defence is, in this case, chemical.

Lymphocytes.

These particular corpuscles, the *lymphocytes*, appear to be closely associated with immunity to disease.

Immunity to Disease.

Immunity may be natural. Certain animals never suffer from certain diseases. Man never has swine-fever. Pigs never have measles.

Immunity may, however, be acquired by the individual.

After one attack of small-pox or chicken-pox, for instance, the individual is not, in normal cases, liable to a second attack.

But there is yet another way in which the individual may gain immunity, and that is by some extraneous means, such as vaccination or inoculation.

When the germs of disease multiply in the body, their harmful influence is manifested by certain poisons, or *toxins* which they cause to accumulate in the blood. The white corpuscles of the blood have the power of producing certain *anti-bodies*, or *anti-toxins*, which unite with the toxins and render them harmless.

Anti-bodies.

To obtain the lymph used in vaccination, a calf is inoculated with small-pox. In the body of the calf the disease-germs are much weaker in character than in the human body. As a result of this, when the calf-serum is introduced into human blood, the disease is produced in a mild form only. It is, however, sufficiently poisonous to induce the blood to produce the specific anti-bodies, and so the individual is fore-armed against an attack of the real disease. That is, he has been made immune.

Vaccination.

In the modern method of inoculation against many diseases it is the poison itself, the toxin, that is introduced into the blood.

Inoculation.

The bacteria responsible for the disease are killed by heat-sterilisation. The dead bacteria are introduced into the blood and are accompanied by a certain amount of the poison they have produced. As the bacteria are dead, they cannot multiply and cause the disease. As, along with the dead bacteria, their particular toxin has been introduced, the blood produces the necessary anti-toxins.

As a rule the process, as it affects human beings, is not so direct as this. The dead bacteria are first injected into the body of some other animal.

In the case of typhoid the horse, because of its size, is generally the subject chosen. The injection of dead bacteria is increased gradually, so that the horse does not suffer. Some of its blood is then extracted. The serum of the blood, containing the anti-

Typhoid Inoculation.

bodies, is separated off and, after further careful treatment, is used for human inoculation.

As anti-bodies continue to be produced in the blood long after the disappearance of the toxins that originally excited them, the effects of inoculation are comparatively lasting. As a rule, the immunity against small-pox lasts for seven years. Inoculation against typhoid must be repeated at the end of three.

One of the most characteristic properties of blood is its power of *clotting*. The formation of clots is the work of leucocytes.

The Clotting of Blood.

In shed blood numbers of small amœboid corpuscles are distinguishable, held together, apparently, by the entanglement of their pseudopodia. These are the *platelets*. It is thought that they play an important part in bringing about the coagulation of blood. Fundamentally the process depends upon the presence in the blood of a soluble protein, *fibrinogen*. Probably the leucocytes secrete enzymes which throw the fibrinogen out of solution, with the formation of solid threads of fibrin. The tangle of these and the corpuscles that they trap mechanically is the *clot*. Clots are always accompanied by a faintly yellow liquid, the *serum*. This is the plasma of blood from which fibrinogen has been removed.

In some country districts it is the practice to put a cobweb on a cut to check bleeding. This it certainly does, but as the cobweb is liable to introduce micro-organisms into the wound, it is not a course to be recommended. A filmy cobweb covers a wound very effectually, and it is a curious fact that contact with some uneven surface provokes clotting. The same result may be more safely obtained by using a chemically clean dressing. This is the explanation of little wisps of cotton-wool that are used to check the bleeding of shaving cuts.

An accessory circulatory system to that of the blood is provided by the lymphatic vessels which conduct the lymph.

Lymph.

The matrix of lymph is the plasma of blood. Through the capillary walls of arteries and veins the colourless plasma of the blood oozes into the body cavity. If this were not collected up, the body and its tissues would become water-logged. This undesirable condition is prevented by drainage into the lymphatics. Their branching capillaries are found in all parts of the body. These unite, forming larger vessels. The largest is the *thoracic duct*, which runs in the dorsal wall of the thorax and opens into the left anterior vena cava.

The lymphatics, then, are carrying a clear fluid. This condition, added to the extreme delicacy of their walls, makes them difficult to trace in dissection. They all enter veins at some point or other, and, in this way, return to the blood-stream waste materials that they have collected from the body.

At intervals in their course little nodules, or *lymph glands*, occur, and in these white corpuscles are produced.

The lymph, then, is not only plasma, but plasma containing leucocytes which are carried to the blood.

Although the name is given to them, the lymph glands of the lymphatic system are not in any way " glands." They do not secrete an enzyme that has some special function to perform.

CHAPTER XVI

THE NERVOUS SYSTEM

In Amœba the nucleus of the cell directs and controls all the activities of the minute animal.

In complex organisms that have a definite digestive tract, a branching vascular system, and active body-members, there is the need for some controlling force to co-ordinate the work of the various organs, so that they are not a mere collection of disconnected parts working individually, but a union of members co-ordinating harmoniously.

Such a co-ordinating force is supplied by the nervous system, which reaches its highest complexity in mammals.

The Brain.

The *central nervous system* consists of the *spinal cord* and the *brain*, the latter being the expanded and elaborated forward region of the cord. The cord is protected by the vertebræ of the backbone and the brain is lodged in the bony skull.

The Cerebral Hemispheres.

The degree of mentality manifested by an individual depends less upon the size than upon the convolutions of the brain, because the whole bulk of the brain is not concerned with thought. Actually the power of thinking depends upon the *cerebral cortex*. This is often spoken of as the *grey matter* of the brain. It covers the *cerebral hemispheres* or *cerebrum*, and the nerve-cells that compose it have a distinctly greyish tint in the mass. In Man the cerebral cortex is not more than $\frac{1}{9}$ of an inch thick, but it is made up of some 9,000,000,000 nerve-cells.

Clearly, the more the cerebral hemispheres are thrown into folds, the greater will be the number of cells of grey matter in the cerebral cortex, because it dips down into all the grooves. Thus the area provided to deal directly with the higher intellectual processes is not only extensive but, at the same time, very compact.

As the brain needs an unfailing supply of oxygen, connective tissue, very richly supplied with blood-vessels overlies the cerebral cortex and follows closely all the convolutions of the cerebral hemispheres. This is the *pia mater*. A thicker tissue, the *dura mater*, forms the outermost covering of the brain, and between these two is the *arachnoid* membrane, which is an extremely delicate layer. In removing the brain from the cranium the greater part of the dura mater is left on the skull.

Together the three tissue-layers that overlap the cerebral cortex are known as the *meninges*. Inflammation of these tissues leads to a great increase in the amount of fluid normally present between the layers, causing the disease known as *meningitis*.

The claim of the phrenologist to connect certain talents with particular " bumps " of the skull apparently has no scientific basis. Physiologists have, however, been able, to some extent, to map out regional areas in the brain itself and indicate the physical and mental processes controlled by certain areas.

The cerebral hemispheres are the seat of all actions that depend upon the will, intelligence, and feeling. If a right-handed person receives an injury to the left cerebral hemisphere, his power of speech is affected. According to the degree of injury, he may merely flounder in speech or be absolutely incapable of uttering sentences. It is by studying cases of injury that the mapping of the brain is made possible. In this case it is clear that the power of speech is located in the left hemisphere. The right hemisphere is the seat of speech in left-handed people.

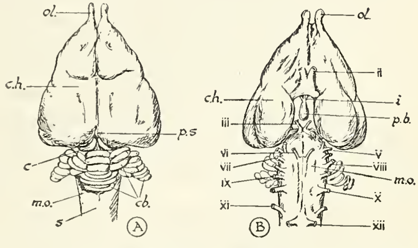


FIG. 116.—The Brain of the Rabbit. A, Dorsal surface. B, Ventral surface. The numbers refer to the paired cranial nerves. *c.*, corpora quadrigemina ; *cb.*, cerebellum ; *c.h.*, cerebral hemisphere ; *i.*, infundibulum ; *m.o.*, medulla oblongata ; *ol.*, olfactory lobe ; *s.*, spinal cord ; *p.b.*, pituitary body ; *p.s.*, pineal stalk.

In the mammal the cerebral hemispheres are so large and extend so far backwards that they cover a great part of the brain (Fig. 116, A).

For this reason the *thalamencephalon*, although it is part of the forward region of the brain, is not seen in a dorsal view, being overhung by the cerebral lobes. The optic nerves, upon which sight depends, pass in the sides of the thalamencephalon, and, for this reason, these parts are called the *optic thalami*. Also, in the thalamencephalon, there are other nerves that come from the posterior part of the body. It seems that, because of these sensory nerves, a certain hazy consciousness is located in the thalami. Such knowledge is gained by a study of abnormal and experimental cases. A dog without cerebral cortex, but with the optic thalami intact, walks about, but bumps clumsily into objects. His whole reaction to the outside world is so dazed that he only eats when food is placed in his mouth.

The Thalamencephalon.

The roof of the thalamencephalon is very thin. In a fish it is plainly seen in dorsal view, because it is not overhung by the cerebrum. Through the transparent roof the cavity of the thalamencephalon is seen.

From the hinder part of the roof there passes backwards a sort of short stalk (Fig. 116, A). This is the stalk of the *pineal body*, one of the ductless glands which protrudes between the hinder ends of the hemispheres. In dissecting, the gland itself is generally torn away with the dura mater, but its stalk remains.

The Pineal Body.

The floor of the thalamencephalon is depressed and prolonged downwards to form the *infundibulum*, which bears another ductless gland, the *pituitary body* (Fig. 116, B).

The Pituitary Body.

The cerebral hemispheres, with the olfactory lobes into which they are prolonged anteriorly, and the thalamencephalon, make up the *fore-brain*. Succeeding this are the regions of the mid-brain and the hind-brain.

In mammals the *mid-brain* is almost completely overhung by the cerebral hemispheres. In the lower animals two *optic lobes* form the roof of the mid-brain. In mammals each of these lobes is divided into two by a transverse cleft, so that four parts are formed, called the *corpora quadrigemina* (Fig. 116, A).

The Mid-Brain.

The roof of the *hind-brain* is the lobed *cerebellum*. The posterior part, behind the cerebellum, is the *medulla oblongata*, which passes backwards into the spinal cord.

The Hind-brain.

It has been shown by experiment that if the fore-brain is removed an animal cannot act on its own initiative, but will carry out complicated actions if it receives the necessary stimulus. A dog eats when food is put into its mouth. A frog will swim when put into water, but left alone it will make no movement.

When the mid-brain is removed and only the hind-brain remains, an animal still carries out a number of reflex actions: it breathes, swallows, and the heart continues to beat.

The Nerves.

It is the work of the nervous system to receive impressions and to respond to them by controlling certain muscles. All the messages are carried by bundles of fibres called nerves, much in the same way as an electric current passes along a transmitting wire.

It is the function of certain nerves to carry sensations *inwards* to the central nervous system. Others conduct impulses *outwards* to the muscles. The former are called *sensory*, or *afferent*, nerves. The latter are *motor*, or *efferent*.

Because every nerve is a bundle of fibres it may be *mixed*, some of its fibres carrying sense-impressions inwards, while others are motor and incite, or inhibit, muscular action.

Sensations carried by nerves are received either by the brain or by the spinal cord. It is therefore in connection with these centres that the most prominent nerves of the body must be studied.

Twelve pairs of *cranial nerves* have their origin in the brain (Fig. 116, B).

The Cranial Nerves.

1. The *olfactory nerves*, that are responsible for the sensations of smell, are bundles of fibres that pass to the nose from the olfactory lobes of the fore-brain.

2. The *optic nerves*, responsible for sight, arise in the corpora quadrigemina and pass along the optic thalami. The nerves from either side meet on the ventral surface of the thalamencephalon, forming the *optic chiasma*. Some of the

fibres cross here, those from the right side going to the left eye, and vice versa. Diverging from the chiasma, each bundle of fibres, the optic nerve, passes through an opening in the bony eye-socket. On the back of the eyeball its cells are the rods and cones forming the retina that receives the impressions of light. As well as conducting the sensations of sight, the optic nerve forms a stalk that holds the ball of the eye in place within the orbit.

3, 4, 6. Three pairs of nerves control the movements of the eye by supplying nerve-fibres to its muscles. These are: 3, the *oculo-motor*, 4, the *pathetic*, and 6, the *abducens*. Just as 1 and 2 are purely afferent, or sensory, nerves, so these three pairs of nerves are purely efferent and conduct impulses outwards.

5. The fifth nerve is called the *trigeminal* because it splits up into three main trunks. Its branches pass in the orbit, or socket, behind the eye, and along the upper and lower jaw. It is partly efferent and controls the muscles concerned in chewing. In its sensory capacity it is largely admonitory, and it is the sensory fibres, distributed to the mouth and face, that are affected in our toothache and neuralgia.

7. The seventh nerve is purely efferent and controls all *facial* expression: smiles, frowns, and the like.

8. The eighth, or *auditory*, nerve is purely sensory. On it hearing depends.

9. The ninth pair of nerves, which are the *glossopharyngeal*, are distributed to the sides of the pharynx and to the back part of the tongue. They are concerned with the sensation of taste.

10. When the tenth nerve leaves the skull it has such a wide distribution that it is called the *vagus*, or wanderer. Its branches are distributed to the larynx, the heart, and the lungs, and even to the liver and alimentary tract. It controls respiration and the beating of the heart, and influences the secretion of digestive juices in the stomach and intestine.

11. The eleventh pair of cranial nerves are distributed to the muscles of the neck.

12. The twelfth, the *hypoglossal*, innervate the muscles of the tongue.

The Spinal Nerves.

In connection with the spinal cord, pairs of nerves branch out between the vertebræ (Fig. 117). Each nerve arises by a dorsal and a ventral root. The dorsal root is sensory, while the ventral root is purely efferent. The two roots unite and immediately split up again into three branches which are mixed nerves. These are in connection with all those parts of the body to which the cranial nerves are not distributed.

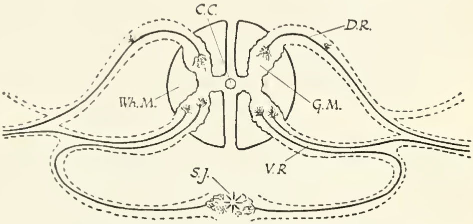


Fig. 117.—Diagram of spinal nerves. *C.C.*, central canal of spinal cord in transverse section; *D.R.*, dorsal root; *G.M.*, grey matter; *S.J.*, sympathetic junction; *V.R.*, ventral root; *Wh.M.*, white matter.

Because of differences in the fibres composing it, nerve tissue appears as *grey matter* and *white matter*.

Grey and White Matter.

In the spinal cord the grey matter is central and the white matter surrounds it. In the brain, on the other hand, the cortex is composed of grey matter and the white matter is enclosed by it.

An interesting point in connection with the cells of the central nervous system is the *decussation* of the nerve-fibres. At some point or other, as it runs forward, every fibre of the spinal cord crosses from one side to the other. Those on the left side of the cord cross to the right side of the brain, and vice versa. This explains why an injury to the left side of the brain may cause local paralysis on the right side of the body; the motor nerves, distributed to the muscles of the right side, have been injured in their cerebral distribution.

Reflex Action.

There are many responses of the nervous system that take place quite apart from the will of the individual. Such an unconscious response is known as a *reflex action*. It occurs, for instance, in the contraction of the pupil of the eye in intense light; in the flow of saliva which makes the mouth water when food is presented ; in the uncontrolled start that follows a sudden noise.

The action and reaction may be represented, in such a case, by what is known as the *reflex arc*, which traces the nerve-path followed in both reception and response. That is, it indicates the course taken by the sensation, its arrival in the central nervous system, its influence on a neighbouring cell that controls motor action, and the transmitting of the message along a motor-fibre to the muscle it controls.

In the contraction of the pupil of the eye, for instance, a nerve-cell of the retina, A, is affected by the light (Fig. 118). An impulse is sent along an elongation of this cell, the elongation being one of the fibres that help to make up the optic nerve. The impulse is received by a cell in the brain, represented as B in the diagram. A contiguous cell, C, is then so influenced that it sends an impulse along its fibre, or axis cylinder, which forms an integral part of the third, fourth, or sixth cranial nerve, as the case may be, and the eye-muscle which is innervated by the nerve makes an appropriate contraction.

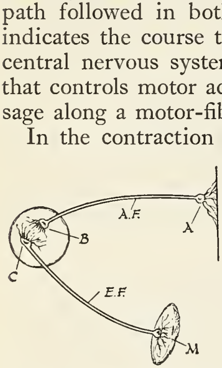


Fig. 118.—Diagram of a reflex arc. *A.*, nerve-cell of retina ; *A.F.*, fibre of sensory nerve ; *B.*, cell that receives the impulse ; *C.*, neighbouring cell influenced ; *E.F.*, motor nerve-fibre, innervating eye-muscle ; *M.*, eye-muscle that contracts.

The whole circuit needs only a flash of time for its completion. Actually such an extremely simple reaction cannot exist, because a stimulus never affects one cell only. It is necessary to think of groups of cells and fibres taking the place of the single cell and fibre named in the illustration.

Other nervous responses depend upon will and consciousness. Their range of complexity varies from a response that is just not a reflex to one that involves deliberation and judgment before action follows, as in crossing the road where traffic is heavy and not well controlled.

Voluntary Action.

In addition to the central nervous system there is, in the body, another system of nerves known as the *sympathetic*.

The Sympathetic System. Two main trunks run right and left of the spinal cord and give off branches which are in connection with corresponding spinal nerves and which pass to the visceral organs of abdomen and thorax.

In the abdomen, quite near the diaphragm, there are so many radiating fibres that this part of the sympathetic system is called the *solar plexus*. It acts as a secondary central nervous system, or abdominal brain, and its position explains why a blow " below the belt " is fraught with danger.

PRACTICAL WORK

The Sheep's brain is the best to study, but it is not easy to get it uninjured. Specially hardened brains can be bought from the dealers. These are expensive, but if they are carefully handled and if, in the intervals, they are kept in 2½ per cent. formalin, they will serve for many lessons. To facilitate removing the brain from the formalin, it should be tied loosely in a piece of butter muslin.

Brain tissue is soft and glandular and soon degenerates. If, therefore, the Rabbit's brain is to be used, a square cut should be made, with bone-forceps, in the skull, at the very beginning of work on the Rabbit. Each time the animal is put back into the formalin, this penetrates into the cranium and the brain is thereby preserved.

To examine the brain, the skin must be removed from the head and the skull carefully chipped away with bone-forceps or a sharp, strong scalpel.

The dorsal surface can be drawn *in situ* and most of the pairs of cranial nerves distinguished. After this, remove the brain by careful insertion of, and pressure with, the handle of a scalpel. Put it into a porcelain basin with water, the ventral surface being uppermost. In this position it is not difficult to complete the drawings of the cranial nerves.

The pairs of spinal nerves are seen by clearing away the tissues in the region of the spinal cord.

CHAPTER XVII

SOME GLANDS AND THEIR WORK

The harmonious working of the body, due to the co-ordination of its parts, depends not only upon nervous control but, also, upon substances discharged into the blood by various glands.

The Liver.

The *liver* is the largest gland in the body, but its work is not only glandular. It acts also as a storehouse for digested food, carried to it by the portal veins. It regulates the amount of sugar in the blood. It prepares the nitrogen-waste which the kidneys expel.

Food is stored in the liver in a compact form as animal starch, or *glycogen*. It is essential that there should be a constant, although somewhat low, percentage of sugar in the blood. If the supply were not regulated there would be excess of sugar in the blood after a meal. For this reason it would be wasted and got rid of by the kidneys. A period would then follow in which the blood was deficient in sugar. Consequently the tissues, all of which need sugar, would be deprived of this food. To prevent such inequality of distribution the liver stores the surplus supply as glycogen. This is converted into sugar (*glucose*) and passed, at need, into the blood-stream, to make good the loss due to sugar-absorption by the tissues.

In the nature of things, liver that is bought from the butcher cannot be absolutely fresh. In the interval preceding its purchase sugar is being formed from the stored glycogen. This chemical change accounts for the sweet taste of the liver we eat.

In the liver, too, a certain number of the red corpuscles of the blood are destroyed. They give the characteristic colour to bile, and also account for the yellowish colour of the fæces expelled at the anus.

Urea.

By the uninitiated, *urea* is looked upon as the very typical product of the kidneys. As a matter of fact it is in the liver that urea is produced. It is formed largely from the waste due to the daily wear and tear of tissues. This explains the increase in excretion as a result of violent exercise or of concentrated mental effort. But the formation of urea also follows certain chemical changes in the excess of amino-acids that were carried, from the intestine to the liver, by the portal vein (p. 158). The urea, prepared by the liver, enters the blood-stream by way of the hepatic veins. It is carried by the blood to the kidneys and there discharged, being conducted by special tubes to the bladder, where it awaits expulsion from the body.

Functioning as a gland, the liver secretes *bile*. When this is needed it passes, by way of the bile duct, to the duodenum (Fig. 107).

The Liver as a Gland.

To some extent the bile is a medium for getting rid of the waste products of metabolism. Probably it plays a more active part in digestion than this, in helping to emulsify fats.

The function of the gall-bladder is uncertain (Fig. 106). It is frequently stated to be a reservoir for the bile. Its small size is against this theory, for in man the most it can hold is about an ounce, which is a totally inadequate amount to be regarded as a store. Further, in some animals there is no gall-bladder. In the horse, for instance, it is missing.

The flow of bile is more or less continuous, but is much nore copious after a meal. The daily flow in a human being s about 500 to 800 c.c. If there is any obstruction to the assage of the bile through the bile-duct, the yellow pigment f the bile is absorbed by the blood, and jaundice results.

In some measure the bile influences the secretion of digestive uices in the pancreas (Fig. 107). Here the chief stimulus is, however, provided by *secretin*, which arises in glands of the duodenal wall and is carried by the lood to the pancreas to stimulate the output of its enzymes. Such chemical messengers are known as *hormones* and play n important part in bringing about co-ordination in the ody.

he Pancreas.

The secretions of both liver and pancreas travel to the uodenum by definite ducts. When a secretion passes from a gland directly to the blood, and does not travel by way of a duct, it is known as an *internal secretion.*

he Ductless lands.

It is the work of the *ductless glands*, or *endocrine glands*, to produce such secretions, which have a far-reaching effect on the body as a whole. As their name implies, these glands pour their secretions, or hormones, directly into the blood-stream, without the intervention of a duct. The particular secretion is then carried by the blood to that part of the body it is designed to influence.

The Thyroid Gland.

In the bunch of offal obtained from the butcher, for the purpose of studying the lungs, trachea, heart, and œsophagus, the *thyroid gland* is very obvious (Fig. 112, B). It consists of two reddish, flattened lobes which lie, one on each side of the larynx, attached to the thyroid cartilage.

This gland secretes a substance called *thyroxin*, which contains 65 per cent. of iodine. If it is not functioning properly the trouble may be that there is a deficiency in the internal secretion; on the other hand, the secretion may be liberated in excess.

In young children a low output on the part of the thyroid gland produces the condition known as cretinism. Growth is stunted and mental development is arrested.

In adults the disease known as myxœdema results. The individual is fat and dull; the hair falls out; the skin is dry and coarse. The metabolic processes have slowed down and the normal oxygen consumption of the body may be reduced to half.

The cure is found by administering thyroid secretion extracted from the glands of lower animals, usually sheep. Such thyroid-feeding must, however, be life-long.

When there is excess of thyroid secretion the gland swells greatly. The metabolism of the body is now super-normal, the oxygen consumption of the individual increasing to practically twice the normal amount. The disease shows itself in protruding eyes, irritability, and general lack of nervous control.

This condition is treated surgically, by the removal of part of the gland.

In many inland districts cases of ordinary goitre result from the nature of the drinking water. The condition is very common in Switzerland. Its prevalence in Derbyshire has given the name of " Derbyshire neck " to this swollen state of the thyroid.

A lack of iodine in food also causes goitre, and the gland grows enormously. In such cases the administration of iodine, in careful doses, reduces the swelling. This is a common prescription for children in Switzerland, where goitre is prevalent.

The experiments carried out on frogs in this connection have already been referred to (p. 92).

It is clear that the metabolic processes of the body are largely regulated by the internal secretion of the thyroid gland. The iodine compound, which is poured into the blood-stream, influences not only the growth of the body, but also the general intellectual development.

The Thymus Gland.

In the same bunch of offal, lying in front of the trachea a little lower down, is a compact body also reddish-brown in colour. This is the *thymus gland.* In the Rabbit it is often seen overlying the heart. It is, however, very variable in size, being bigger in young animals than in old ones. Its function is unknown. Probably it controls pre-natal development to some extent.

In adult man it has normally disappeared. In abnormal cases where it persists, the individual seems unable to resist sudden shock. A motor-car collision, for instance, without any apparent injury, may be sufficient to cause death.

The Adrenal Glands.

In a dissection of the Rabbit it is easy to see the *supra-renal*, or *adrenal, glands.* They are round, yellowish masses of tissue that lie one in front of each kidney (Fig. 114). Their secretion is *adrenalin.* It is produced in excess during emotion, as in fear or anger. The secretion is arrested in a case of sudden shock. The flesh then " creeps," because blood is diverted from the skin, and hair " stands on end " (p. 222).

Apparently the effect of adrenalin is to regulate blood-pressure. Recent work has shown that deficiency in this secretion results in nervousness and fear.

In the brain, the floor of the thalamencephalon is depressed and prolonged to form the infundibulum, which bears the *pituitary body* (Fig. 116).

The Pituitary Body.

The posterior lobe of this gland produces a hormone known as *pituitrin*, which influences muscular contraction.

The secretion of the anterior lobe of the gland influences growth as a whole. If there is an excess of this secretion the condition known as acromegaly results. This is a deformity of bone, manifesting itself in the enormous growth of hands and feet, and of the lower jaw of the skull.

In the case of giants, hyper-secretion has taken place during the period of growth in length of the bones, resulting in their abnormal dimensions.

Deficiency in the secretion stunts growth in height and produces abnormal fatness.

The Pineal Body.

Projecting from the dorsal surface of the brain is the *pineal body* (Fig. 116). It resembles a minute cone in shape. It is said to represent a median eye.

In the New Zealand lizard-like reptile, Hatteria, there is an arrangement of rods and cones in the pineal body, resembling the arrangement of cells in the retina of the normal eye of vertebrates (p. 233).

The function of the pineal gland is by no means understood. Apparently it influences the development of the reproductive organs.

The Reproductive Organs.

The *reproductive organs* are themselves to be regarded as ductless glands. Apart from the fact that the ovaries produce eggs and the testes sperms, they give out secretions which have great influence on development in widely separated parts of the body. They influence, for instance, the growth of hair in various parts, and the change in the *timbre* of the voice. The growth of horns, antlers, mane, and so on, is controlled by the secretions of the reproductive organs.

The Spleen.

Strictly speaking, the *spleen* is not one of the glands, but it is convenient to study it in connection with these.

It is an obvious structure in the Rabbit. It lies behind the stomach and is attached to it at the end nearest the œsophagus.

Its great work is the destruction of the red corpuscles of the blood. In Man it is normally about 5 inches long. In diseases such as malaria and pernicious anæmia it increases enormously in size. In the former case it sometimes weighs as much as 10 pounds.

Multiplication of the white corpuscles of the blood apparently occurs in the spleen, as well as in the lymph-glands. It has been stated that red corpuscles also multiply in this organ. This may be so in the embryo, but there is no authority for the statement as far as adults are concerned.

The Tonsils.

At the back of the soft palate, one on either side, are two small pits which are the *tonsils*. Their use is very obscure. They often give a good deal of trouble by becoming diseased and causing deafness and various throat troubles. Like all glandular tissue, they have a rich supply of blood-vessels and lymphatics. They are active centres for the production of lymphocytes, and it may be that they exercise some sort of protection against micro-organisms.

CHAPTER XVIII

VITAMINS

The researches of recent years have revealed that in a still further sense " Man can not live by bread alone." Above and beyond the actual carbohydrates, proteins, and fats, that compose the food of animals, additional factors are essential in metabolic processes. These additional factors are the *vitamins*, now so well known to all by name.

As a result of most detailed experiments, five vitamins have been distinguished, according to their distribution and their effect upon animal organisms.

For their origin they all agree in being dependent upon chlorophyll-containing plants. A plant grown in the dark does not produce them. Animals obtain the vitamins indirectly by eating vegetable food.

The milk of cows in summer-time, when they are grazing, is rich in vitamins. They are absent from the milk of the same cows in winter-time, if they are being fed on artificial foods.

Vitamin A.

Vitamin A is fat-soluble and is found in fats of animal origin, as in butter, cream, beef-fat, and cod-liver oil. It is interesting to note its absence in lard, and to correlate this with the fact that pigs do not eat grass. The fat of fishes is very rich in vitamins.

Vitamin A occurs also in eggs, in embryos of seeds, and in green vegetables.

Curiously it is absent from almost all vegetable fats, except palm-oil, which is utterly unfit for human consumption. This lack in vegetable fats explains why vitamins are absent in cheap margarines.

This particular vitamin is essential for the healthy growth of young animals in particular. Eye-trouble results from the lack of it in food. Evidently it affects the blood directly, because its shortage causes loss of immunity to various diseases.

Vitamin B.

Vitamin B has a very wide distribution. It is water-soluble and is found in most natural foodstuffs. In cereals it occurs in the embryo and in the layer of the grain immediately within the pericarp (p. 399). It occurs in eggs, yeast, to some extent in milk, and in most vegetables.

Like Vitamin A, it is not destroyed by boiling, unless the operation be unduly prolonged.

This vitamin is essential for health at all stages of growth. Its absence leads to constipation and nervous affections.

The disease *beri-beri* is caused when polished rice is the staple food. The rice-grain is a caryopsis (p. 399), and Vitamin B occurs just within the fused coat of pericarp and testa. In the polishing process this vitamin-containing layer of the grain is removed. Beri-beri is a complex infirmity, including neuritis, paralysis, nervous affections generally, and, in many cases, dropsy.

Vitamin C.

Vitamin C is water-soluble. It is present in fresh vegetables and in some fruits. It occurs in tomatoes, lemons, and oranges, for instance, but not in limes. Its absence leads to scurvy, which was formerly such a scourge on long voyages, because this vitamin disappears completely in all canned and preserved food. Apparently its disappearance depends upon the fact that it only occurs in those parts of plants in which metabolic changes are actively taking place. It is not, for instance, found in seeds.

Bottle-fed babies sometimes develop scurvy, because their milk has been over-boiled and the vitamin destroyed. Giving orange- or grape-juice regularly, counteracts the deficiency of the vitamin in the milk.

Vitamin D is fat-soluble and has much the same distribution as A.

Vitamin D.

In its absence young animals are rickety and have bad teeth. It appears in tissues that are subjected to ultra-violet rays; therefore its deficiency may be made good by prolonged exposure of the skin to sunlight or to ultra-violet rays. In this fact is the key to the value of sun-bathing. Monkeys delight in the ultra-violet rays provided for them at the Zoo.

Vitamin E.

Vitamin E is fat-soluble, but it does not occur in cod-liver oil. Neither is it found in orange-juice. It is present in lettuces and green leaves generally, in wheat, and in milk.

Apparently its absence affects the reproductive organs and leads to sterility. No young rats were born of female rats that had been brought up on a diet deficient in Vitamin E.

A study of the vitamins and their far-reaching influence makes it clear that animals, just as much as plants, need light, or products depending upon the action of light, for their well-being. If a direct supply is not available, then they must obtain these products indirectly, through the agency of plants.

CHAPTER XIX

THE MUSCLES AND SKELETON

In all animals, from Amœba upwards, it is mainly by muscular response that the organism can keep in harmony with its environment. The response may depend upon invisible fibrils of the protoplasm, as in primitive types; or, as in more complex animals, upon the ordered working of masses of muscle-tissue which, in Vertebrates, are attached to bone either directly, or indirectly by means of tendons.

It is these bones that make up the endoskeleton of higher animals. They give steady support to the various parts of the body and form a protective case, enclosing the more delicate internal organs.

The bony framework of the Rabbit is an easy object to study. Prepared skeletons are not expensive to buy, and it is not difficult, by further boiling, to obtain a well-cleaned series of bones from an animal that has been used for food.

More than any other part of the mammalian body, the skeleton shows that bilateral symmetry which is such a striking characteristic of the Earthworm. Like the Earthworm, too, but unlike the rest of the body of the mammal, it is metamerically segmented. The main axis of the skeleton comprises the segmented vertebral column and the skull. The limbs, attached to the limb-girdles, are the symmetrical appendages of the skeleton.

The Spinal Column.

The segments of the spine are the *vertebræ*. The whole *spinal column* is flexible, because of its segmented character. It is firm, because the vertebræ are joined by *ligaments* of connective tissue. At the same time the bones are prevented from rubbing one upon another by plates of cartilage which form the *intervertebral disks*.

A neural canal is present in each vertebra, and the spinal cord runs in the tube formed by this series of canals.

From the skull to the tail the vertebræ fall naturally into five groups. Along with a certain diversity in form there is, fortunately, a strong background of uniformity. If, therefore, a vertebra from one region be first studied in detail, the points of difference in those of other groups are quickly learned.

The General Plan of Vertebræ.

In every vertebra, except at the tip of the tail, there is the large cavity of the *neural canal.* A solid, bony mass, the *centrum*, forms its floor. Its sides and roof are formed by the *neural arch*, which is prolonged upwards as the *neural spine* (Fig. 119).

As pairs of spinal nerves leave the nerve-cord throughout its entire length, some provision must be made for their escape between neighbouring vertebræ. For this reason there are *intervertebral notches*, on both faces of the neural arch, near the centrum. Of these the posterior notch is the deeper. The notches of proximal vertebræ coincide, and the spinal-nerves pass through the gaps thus formed.

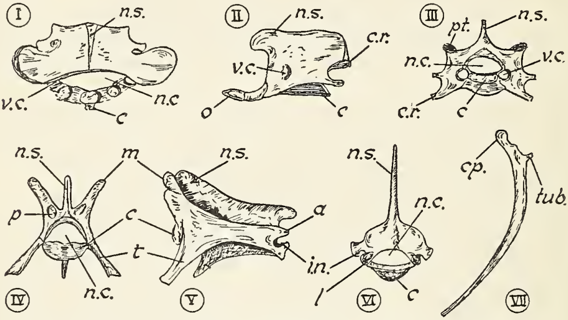


FIG. 119 (I–VI).—Vertebræ of Rabbit. I, Atlas. II, Axis. III, Cervical. IV, Lumbar (from the front). V, Lumbar (from the side). VI, Thoracic. VII, One rib. *a.*, anapophysis; *c.*, centrum; *cp.*, capitulum of rib; *c.r.*, cervical rib; *i.n.*, intervertebral notch; *m.*, metapophysis; *n.c.*, neural canal; *n.s.*, neural spine; *o.*, odontoid process; *p.*, prezygapophysis; *pt.*, postzygapophysis; *t.*, transverse process; *tub.*, tuberculum of rib; *v.c.*, vertebrarterial canal.

From either side of the centrum, *transverse processes* of flattened bone project downwards. They serve for the attachment of muscles.

As the back may be bent forwards and sideways and turned from right to left, something in the structure must be designed to permit the movement of one vertebra upon another. This is provided for by articulating processes called *zygapophyses*.

The two anterior, or *prezygapophyses*, point upwards and turn inwards towards each other. The actual articulating surfaces are somewhat concave.

The posterior processes, or *postzygapophyses*, of the vertebra in front must, therefore, project backwards. Their articulating surfaces must be slightly convex and face outwards.

This device makes possible the interlocking of the vertebræ and allows for a limited range of movement.

In the neck there are seven *cervical vertebræ*. This number is constant in all mammals, even in the long-necked Giraffe and the short-necked Whale.

Cervical Vertebræ.

Their distinguishing characteristics are the two *vertebrarterial canals*, one on either side of the centrum. Through these, on each side of the body, a branch of the subclavian artery passes to the brain (Fig. 119).

From their position it is natural to conclude that the canals are perforations of the transverse processes. This is not the case. Actually in this region the transverse processes are very short. Before birth small ribs are connected with the vertebræ of the neck. During pre-natal life these *cervical ribs* become fused with the vertebræ, leaving just a little gap between centrum and rib. This gap is the vertebrarterial canal.

The first cervical vertebra, the *atlas*, articulates directly with the skull, and is very different from the others (Fig. 119).

The Atlas.

The neural canal is very large. In life a ligament stretches across it, so that two passages are formed, the upper one lodging the spinal cord. In a prepared skeleton the ligament is often missing.

Only a very narrow floor of bone represents the centrum. The neural spine is an inconspicuous ridge. The transverse processes are wide and spreading. The prezygapophyses are deeply concave to accommodate the *condyles* of the skull. In nodding, the head is moving in these grooves.

The Axis.

The *axis*, or second cervical vertebra, also has individual characteristics (Fig. 119). Of these the most pronounced is a forward, tooth-like projection from its centrum. This is the *odontoid process*. It is the missing portion of the centrum of the atlas, that has fused with the centrum of the axis during development.

Large convex facets of the axis fit into concavities of the atlas. The odontoid process rests on the floor of the atlas and acts as a pivot, allowing head movements to the right and left. This sideways movement is quite independent of the atlas, which moves with the head.

The Thoracic Vertebræ.

The cervical vertebræ are followed by the *thoracic*, which generally number twelve, but sometimes there are thirteen. They have particularly long neural spines. Of these the first nine slope backwards ; the tenth is almost vertical ; the remaining two or three point forwards.

There are additional facets on the thoracic vertebræ, because the *ribs* articulate with them by means of two processes. One of these, the *tuberculum* of the rib, meets a facet on the under-surface of the transverse process of the vertebra. The other, the *capitulum*, or head, articulates between the centrum of this vertebra and the one that precedes it (Fig. 119).

The Lumbar Vertebræ.

The *lumbar vertebræ* follow the thoracic. Their number depends upon the number in the thoracic region and is either seven or six (Fig. 119).

Their transverse processes have two limbs, one of which points upwards and is called the *metapophysis*. The first two of the series also have an additional downward projection from the centrum, called the *hypapophysis*. All have backward projections from the neural arch, just above the intervertebral notch. These are the *anapophyses*.

The Sacrum.

Following the lumbars are the fused vertebræ of the *sacrum* (Fig. 122).

The transverse processes of the first two articulate with the pelvis. Strictly speaking, these are the only two sacral vertebræ. It is usual, however, to apply the term " sacrum " to the varying number of vertebræ, generally four or five, which are found together in this region.

The Caudal Vertebræ.

The small *caudal vertebræ* of the tail are about sixteen in number. As they are traced backwards in the body, they are seen to lose all vertebral characteristics. Finally even the neural canal disappears, and the last vertebræ are reduced to tiny centra.

The dorsal part of each *rib* is composed of bone, and this is the greater part. The ventral extension of each is of cartilage.

The Ribs and Sternum.

As the ribs help to enclose the thoracic cavity, they are attached ventrally as well as dorsally. Their dorsal attachment is to vertebræ. Their ventral attachment is to the breast-bone, or *sternum* (Fig. 120). This forms the median, ventral wall of the thorax, and is made up of segments, or *sternebræ*. The *manubrium* is the first of these and is much the largest. The sixth segment and last sternebra is a slender bony rod, called the *xiphisternum*, which ends in cartilage.

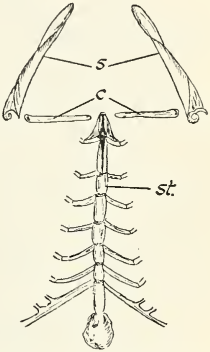


FIG. 120. — Diagram to show the relative positions of shoulder-blade, collar-bone, and breast-bone in the Rabbit. *c.*, clavicle; *s.*, scapula; *st.*, sternum.

The first seven pairs of ribs articulate directly with the sternum. The next two pairs are not connected with the sternum, but with the ribs in front of them. The remaining three pairs are the floating ribs. These are connected neither with the sternum nor with their neighbours, but with the backbone only. They differ a little, too, in their vertebral attachment, for they have no tubercles and articulate with, not between, the centra.

The Pentadactyl Limb.

In fishes the paired limbs are fins. The skeleton of the fin is made up of a cartilaginous plate supporting fin-rays. On dry land such limbs would be useless; therefore a different type of limb is characteristic of land animals. This is the *pentadactyl limb*, so called because it ends in five digits, either fingers or toes.

The typical pentadactyl limb consists of a long proximal bone, extending from the axial skeleton. This articulates with two separate bones, which, in their turn, are followed by a group of ten bones arranged in three rows: three in the first row, two in the next, and five in the next. Five longer bones follow these, and are covered with the flesh of the palm of the hand or the sole of the foot. Beyond these, again, are five digits.

This is the typical, primitive structure, the original ground plan of the limb, from which have been derived the variations characteristic of the limbs of Amphibia, Reptiles, Birds, and Mammals.

These variations are manifold. In the Horse, for instance, only one perfect toe remains (p. 128). Although there are five digits in the fore-paw of the Rabbit, the hind-paw has only four. In the Frog, instead of the two long separate bones of the typical fore-limb, there is only one; but a groove, running along the bone, is an indication of its dual origin. In Birds there is great reduction in the carpals and digits of the fore-limb which is the wing (p. 107). The thumb and the second finger are present, each represented by one joint. The first finger has two phalanges. The other digits are absent.

The Fore-Limb.

The fore-limb of the Rabbit corresponds to the arm of Man, but does not carry out the varied movements of our upper limb. Its position in relation to the axial skeleton can be imitated by stretching the right arm sideways with the thumb upwards. A right-angled bend at the elbow will bring the fingers pointing forwards. By a stiff downward movement the whole arm may be brought to the side. A rotation of the hand, so that the thumb points inwards and the palm downwards, will now give that prone position of the hand which is the permanent condition in the Rabbit.

The Humerus, Radius, and Ulna.

The large, proximal bone of the fore-limb is the *humerus* (Fig. 121). The two bones of the forearm, with which the humerus articulates at the elbow-joint, are the *radius* and *ulna*.

The radius leads directly to the thumb. In Man the radius can radiate over the ulna. If the right arm, with the palm of the hand upwards, is held by the left hand midway between wrist and elbow, the rotation of radius on ulna is felt when the hand is turned to make the palm face inwards, then downwards.

Although in the Rabbit the radius and ulna are not fused, as in the Frog, they are articulated in such a way that they

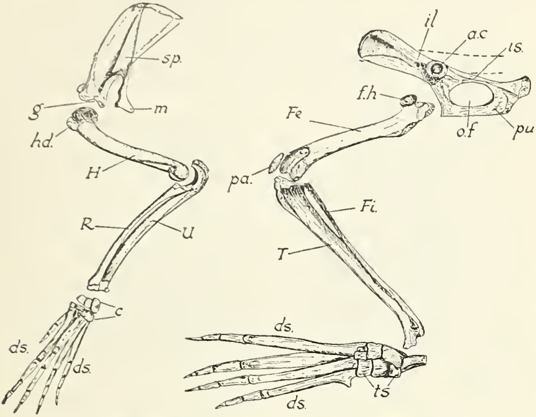


Fig. 121.—Diagram of limbs and limb-girdles of the Rabbit. *ac.*, acetabulum; *c.*, left wrist; *ds.*, digits; *Fe.*, femur; *Fi.*, fibula; *f.h.*, head of femur that fits into the acetabulum; *g.*, glenoid cavity; *H.*, humerus; *hd.*, head that articulates with glenoid cavity; *il.*, ilium; *is.*, ischium; *m.*, metacromion; *o.f.*, obturator foramen of left half of pelvis; *pa.*, knee-cap; *pu.*, pubis; *R.*, radius; *sp.*, spine of left scapula; *T.*, tibia; *ts.*, left ankle; *U.*, ulna.

annot move one upon the other. They are, however, just lightly crossed.

A backward projection of the ulna, the *olecranon process*, nakes this bone longer than the radius (Fig. 121). The lecranon process is curved, and the notch thus formed works ulley-wise in, and over, the distal end of the humerus, which s deeply grooved. This groove is called the *olecranon fossa.* he curved olecranon process and the olecranon fossa in which it works together make the easy-moving, serviceable elbow-joint.

At the other end of the humerus, near its head, there is a longitudinal groove in which the tendon of the biceps muscle fits. It is bounded by two ridges of bone, which are the *greater and lesser tuberosities*. When the humerus is seen alone, these give the clue as to whether the bone belongs to the right limb or the left, because the greater tuberosity is on the outer side of the humerus and extends, as a delta-shaped ridge on its anterior surface, as far as the middle of the shaft of the bone.

Instead of ten bones, as in the typical pentadactyl limb, there are only eight in the Rabbit's wrist. The explanation is that a fusion of some of the bones has taken place. The wrist bones are called *carpals* (Fig. 121). The names of the first three are determined by their relation to the bones of the fore-arm. The *radiale* and *ulnare* articulate with radius and ulna respectively. Between them is the *intermedium*. The next row has one bone only, the *centrale*, possibly formed by the fusion of two. In the third row the fourth and fifth distal bones have fused together, so that four bones occur here instead of five.

Beyond the wrist is the hand. Rod-like bones, called *metacarpals*, support the fingers, which are made up of three *phalanges* except in the pre-axial digit, or thumb, which has only two.

The connection of the fore-limb with the axial column is made by way of the shoulder-blade, or *scapula*, whose general shape is familiar to everyone who has carved a shoulder of mutton (Fig. 121).

The Pectoral Girdle.

The scapula is triangular. Its apex, which points forwards and downwards, is grooved to accommodate the head of the humerus and so form a joint. A prominent spine runs downwards on the outer surface of the scapula and ends in a backwardly directed process, called the *metacromium*. Strong muscles are attached to both sides of this ridge and give the arm and shoulder-blade their range of movement. These muscles are carved into slices when the lean meat of a shoulder of mutton is cut. It is these muscles, too, together with certain tendons, that attach the fore-limb of the animal to the ribs and thoracic vertebræ and so give it its fixed position.

The remaining part of this limb-girdle, or *pectoral girdle*, is the collar-bone, or *clavicle* (Fig. 120).

In the Rabbit this is a small curved bone, attached at one end to the end of the spine of the scapula, at the other to the manubrium of the sternum. As its chief use is to support the arms, it is developed most strongly in animals whose fore-limbs carry out a wide range of movement. Thus its absence is explained in Donkeys, Cows, and Horses, which only use their fore-limbs in locomotion. As Dogs, Rabbits, and Cats use their arms in various operations, they all have a small clavicle. In Birds the clavicle is the "merry-thought." In ourselves it is much more strongly developed than in other animals, because we do so much work with the two fore-limbs of the body.

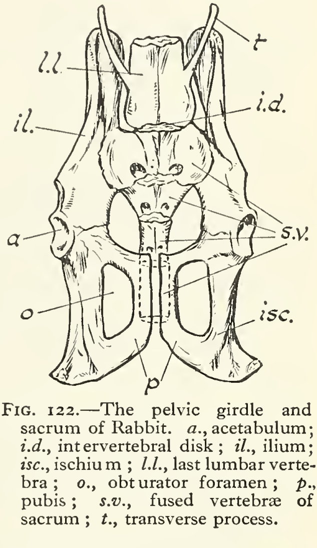


Fig. 122.—The pelvic girdle and sacrum of Rabbit. *a.*, acetabulum; *i.d.*, intervertebral disk; *il.*, ilium; *isc.*, ischium; *l.l.*, last lumbar vertebra; *o.*, obturator foramen; *p.*, pubis; *s.v.*, fused vertebræ of sacrum; *t.*, transverse process.

The Pelvic Girdle.

The hip girdle, or *pelvic girdle*, which supports the hind-limbs, is much more rigid and its bones are much more united, than is the case in the pectoral girdle.

The hip girdle consists of two halves, each of which is very firmly attached to the sacrum, forming with it the ring that is called the *pelvis* (Fig. 122).

Apart from the sacrum, the pelvic girdle is made up of three bones: the *ilium*, the *ischium*, and the *pubis*. It is only in very young skeletons that the boundaries of the individual bones are seen. The three bones meet at the *acetabulum*, the deep cavity in which the head of the thigh-bone moves. A little way in front of the acetabulum the ilium is roughened for articulation with the sacrum. The strong muscles of the buttock are attached to its dorsal and anterior edges. Powerful muscles at the back of the thigh are attached to roughened projections of the ischium. The pubis of each side of the body meets its fellow in the median plane and, with the ischium, encloses a large oval space, the *obturator foramen*, through which certain nerves and blood-vessels pass to the legs (Fig. 122).

The Rabbit's hind-limb is more used in locomotion than the fore-limb and is bigger, but its construction follows the same plan.

The Hind-limbs.

The single proximal bone is the *femur*, or thigh, whose prominent rounded head fits closely into the acetabulum, as a ball fits into a socket (Fig. 121). It is held in position by strong ligaments. In the neighbourhood of the head of the femur three rough projections, called *trochanters*, support the muscles that are concerned with leg movements. The bone widens at its distal end, bearing two large, rounded condyles for articulation with the tibia. A deep groove, the *intercondylar groove*, separates the articulating surfaces.

The two bones of the fore-leg are very unequal in size, for the *tibia* is the longest bone in the body, while the *fibula* is small and fragile and soon loses its separate identity, becoming fused with the tibia about the middle of the shaft of the bone (Fig. 121).

The fibula is the outer bone of the leg. In ourselves, although it is small, it is quite definitely an individual bone, extending from the knee to the tarsals, where it forms the lump on the outer side of the ankle.

Capping the junction of femur and tibia is the *patella*, or knee-cap (Fig. 121). It has been formed by the transformation of tendon into bone at this point. When the knee bends it slides in the deep groove of the femur, that lies between the condyles.

The proximal end of the tibia articulates with the condyles of the thigh. A prominent crest, which in us is the shin, marks the upper part of the front of the bone, whose distal end articulates with the *tarsals*. These are the bones of the foot that correspond to the carpals of the wrist.

The primitive ten bones of the pentadactyl limb are in the Rabbit reduced to six. In Man seven tarsals persist.

The six bones are arranged in two rows, with a central bone between them. The first row is made up of two bones, the *astragalus* and the *calcaneum*. The latter projects backwards as the heel. Because of the shortness of the fibula, both bones articulate with the tibia. The central bone occupies a central position, and the three remaining tarsals are arranged in a straight row (Fig. 121).

There are only four toes in the Rabbit's foot. Except for a slight, bony projection that marks its position, the digit that corresponds to our big toe has completely disappeared. Only in a very young skeleton is it present as a separate bone.

Joints.

Bones meeting to form joints are to some extent kept in place by the muscles attached to them ; but bands of gristle are specially designed to strengthen the connection. These bands are the *ligaments*. The word is derived from the Latin *ligamentum*, a bandage.

When joints are " put out," one bone has slipped from the connection, with displacement of the ligaments. In a bad dislocation the ligaments are often torn.

So that there may be no friction in the working of joints, they are bathed in a lubricating fluid, the *synovial fluid*, secreted by a thin membrane, the *synovial membrane*. The ends of the bones of joints are capped by a thin layer of cartilage and the synovial membrane overlies the cartilage.

This condition obtains in those joints, known as *imperfect joints*, where but little movement takes place, as in the backbone.

In others, where a greater degree of movement is possible, that is, in the *perfect joints*, there is in addition a definite capsule, or *synovial chamber*, in which the fluid is produced and held. The chamber is formed by the outermost sheath, the *periosteum*, of one bone passing over the joint, so that it is in continuity with the outermost sheath of the bone with which it articulates.

The wall of the chamber thus formed is lined with the same synovial membrane that caps the ends of the bones.

When a joint is injured there is often an increased output of synovial fluid. " Water on the knee " is a common accompaniment of a displaced patella, or knee-cap.

With age the synovial membrane ceases to function perfectly. The easy movement of youth is lost. The joints are then stiff, and creaking often accompanies movements.

In the periosteum are the larger blood-vessels of the bone. Their smaller branches run in the numerous canals that riddle the bone, and supply the bone itself and the internal marrow cavity, when this is present, with blood.

Growth of Bone.

Mammalian bones grow in three distinct regions. In the vertebræ, for instance, and in the long bones of the skeleton, there is a growing area at each end, as well as in the main part of the bone. The ends are called *epiphyses*, and are separated from the main part of the bone by cartilage. It is here that growth in length of the bone takes place. When the bone has reached its full size, this layer of cartilage also ossifies, that is, becomes bone.

In the skeleton of a young mammal the epiphyses readily separate from the shaft of the bone. In adults the line of separation is obliterated. In ourselves complete ossification has generally taken place at about eighteen years of age. In this fact lies the value of X-ray photographs in determining the youth of Tutankhamen.

When the pituitary gland is over-active during the growth period of an individual, the ossification of the cartilage of the epiphyses is much delayed (p. 198). The bones grow abnormally and the individual becomes a giant. Acromegaly is the growth of the bone in thickness. It is caused by over-secretion of the pituitary gland when growth in height has ceased.

The Skull.

Because of its size a Dog's skull is a more satisfactory object of study than the Rabbit's, and it is easily obtainable. One skull should be cut longitudinally to show the internal appearance of its parts.

Three regions are distinguishable in the skull : the *cranium*, which lodges the brain, the *nasal apparatus*, and the *jaws*. The two latter make up the *face*.

The Cranium.

The cranium consists of three rings of bone : the *occipital*, the *parietal*, and the *frontal* rings. The bones of these rings form the floor, the sides, and the roof of the brain-case (Fig. 123, A).

The occipital ring surrounds a hole, the *foramen magnum*, through which the spinal cord passes to the brain (Fig. 124, C). The floor of the ring is a somewhat hexagonal bone, the *basi-occipital*.

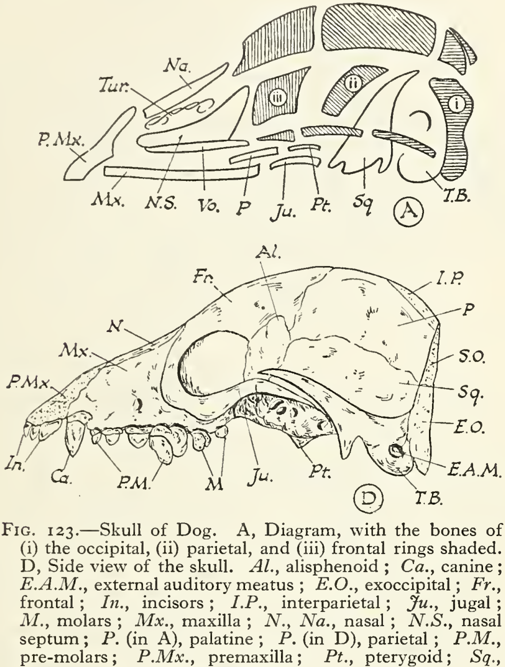


FIG. 123.—Skull of Dog. A, Diagram, with the bones of (i) the occipital, (ii) parietal, and (iii) frontal rings shaded. D, Side view of the skull. *Al.*, alisphenoid ; *Ca.*, canine ; *E.A.M.*, external auditory meatus ; *E.O.*, exoccipital ; *Fr.*, frontal ; *In.*, incisors ; *I.P.*, interparietal ; *Ju.*, jugal ; *M.*, molars ; *Mx.*, maxilla ; *N.*, *Na.*, nasal ; *N.S.*, nasal septum ; *P.* (in A), palatine ; *P.* (in D), parietal ; *P.M.*, pre-molars ; *P.Mx.*, premaxilla ; *Pt.*, pterygoid ; *Sq.*, squamosal ; *S.O.*, supraoccipital ; *T.B.*, tympanic bulla ; *Tur.*, turbinals ; *Vo.*, vomer.

Rising vertically upwards on either side of it are the *ex-*

occipitals, which are continued backwards as curved condyles, for fitting into the two grooves of the atlas which support the skull. The *supraoccipital*, that completes the ring, is a flat vertical bone.

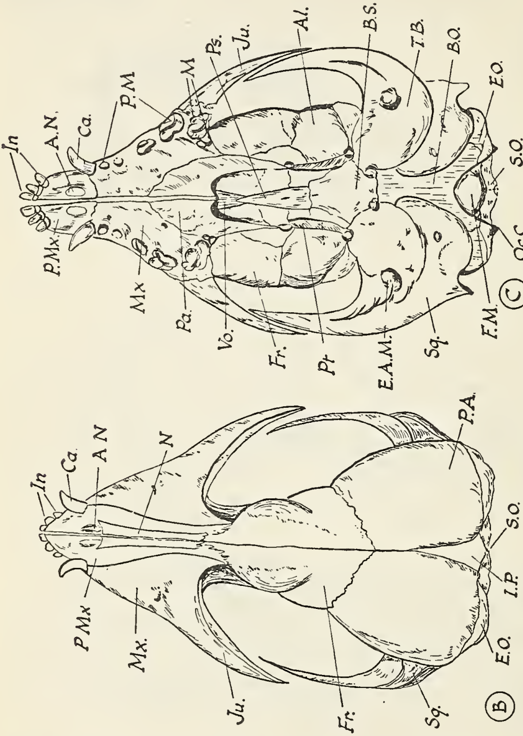


FIG. 124.—Skull of Dog. B, Dorsal view. C, Ventral view. *An.*, anterior nares; *B.O.*, basioccipital; *B.S.*, basisphenoid; *F.M.*, foramen magnum; *Oc.C.*, occipital condyle; *Pa.*, palatine; *P.A.*, parietal; *Ps.*, presphenoid; the other lettering as in Fig. 123.

The basal bone of the parietal ring is the *basisphenoid* (Fig. 124, C). This is grooved, internally, to lodge the pituitary body. From its sides the wing-like *alisphenoids* arise. This ring is completed dorsally by two *parietals*.

Dorsally and ventrally the parietal ring touches the occipital ring. The connection is interrupted laterally by the *squamosal* bone of each side (Fig. 123). In mammals this is a most important bone, for the lower jaw articulates with it.

The third and anterior ring of the cranium is the frontal. Its floor is the *presphenoid*, its sides the *orbitosphenoids*, and its roof the *frontals*, that form our forehead. They compose a large part of the wall of the orbit in which the eye rests. The boundary of the orbit is completed by the *ali-* and *orbitosphenoids*.

The skull-bones have irregular margins that dove-tail one into another in a zigzag fashion. In a young skull they can be made to separate perfectly by filling the cranial cavity with dry peas. If muslin is tied over the skull to close the foramen magnum, and the whole then immersed in water, the swelling of the peas and consequent great pressure on the individual bones, forces these apart.

This zigzagging of the bones is interrupted here and there by gaps through which many of the cranial nerves pass to their special distribution.

Also, between the exoccipitals and alisphenoids the *periotic* bone is wedged in (Fig. 125, E). This encloses the internal ear (p. 226). In an external view of the skull it is overshadowed by the prominent *tympanic bulla*, across whose cavity pass the small bones of the middle ear (Fig. 127).

The Face.

The face is separated from the cranium by the *cribriform plate*. This bone is riddled with holes through which the fibres of the olfactory nerves pass from the olfactory capsule of the brain to the nose. A median plate of cartilage divides the nose into two cavities, or nostrils. They are roofed in by two longitudinal bones, the *nasals* (Fig. 124, A). These dove-tail into the frontals posteriorly.

The fibres of the olfactory nerve end in the special olfactory cells of the thin membrane that lines the scroll-bones of the nostrils (p. 172).

The Jaws.

Four bones, all bearing teeth, form the upper jaw. The two small ones in front are the *premaxillæ* (Fig. 123). Behind these are the *maxillæ*, which form a large part of the skeleton of the face.

A short stout projection, directed backwards from each maxilla, meets the cheek-bone—the *malar*, or *jugal*. The arch, thus partially formed, is completed by a forward process from the squamosal bone on each side of the face. This is the *zygomatic arch* and completes the boundary of the orbit (Fig. 123).

On the under-surface of the zygomatic process of the squamosal, just in front of the bulla, is the grooved *glenoid* *facet* for articulation with the lower jaw, or *mandible* (Fig. 125). The projection directed downwards behind this facet, the *postglenoid process*, is much more strongly developed in the lower animals than in ourselves, with the result that in yawning they never dislocate the jaw.

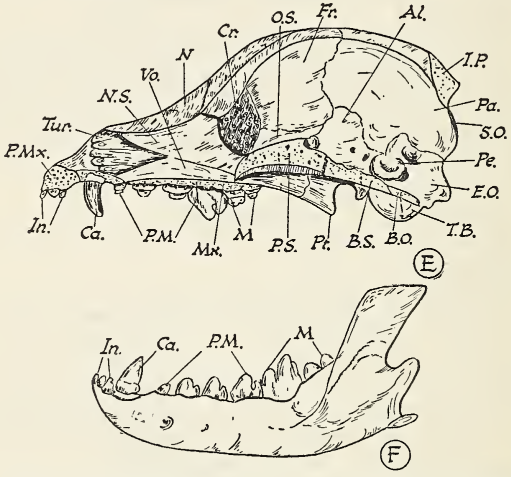


Fig. 125.—E, Median section of skull of Dog. F, Lower jaw. *Cr.*, cribriform plate ; *O.S.*, orbitosphenoid ; *Pe.*, periotic ; the other lettering as in Figs. 123, 124.

Flat horizontal extensions of the maxillæ meet in the middle line to form part of the hard palate, which is completed by the *palatines* (Fig. 124, C). Thus the mouth is roofed in.

Extensions of the palatines run backwards as ridges, one on either side of the pre- and basisphenoids. Where the posterior ends of these ridges meet the basi- and alisphenoids, there are two narrow angular bones, the *pterygoids* (Fig. 123, D).

As well as forming the roof of the mouth, the maxillæ and premaxillæ bound the sides of the nasal passage. In addition to the two long narrow nasals that form its dorsal boundary, there is a median bone, the *vomer*, that forms its floor (Fig. 125, E). The two cavities into which this passage is divided by the nasal septum, or *mesethmoid*, contain the scroll-bones or *turbinals* (Fig. 125, E).

The Hyoid.

If the neck, just below the chin, is spanned by the thumb and first-finger, then firmly pressed, an unpleasant pain is felt. The pressure is being exerted on the *hyoid* apparatus—a series of small rod-like bones which support the tongue. The main *body of the hyoid* is just in front of the larynx, and it is connected by ligaments with the thyroid cartilage (p. 174).

On either side of the body of the hyoid there are two horns, or *cornua*. The longer of these are posterior and extend obliquely upwards. The anterior and posterior cornua of each side are connected with the skull by delicate muscles.

In the Dog the anterior cornua are much longer than the posterior and consist of three elements.

The small bones of the hyoid apparatus are often found in tongues of Sheep and Oxen that have been tinned or otherwise prepared for table use.

PRACTICAL WORK

It is advisable to have one prepared skeleton of the Rabbit, preferably disarticulated.

This may be supplemented with any bones that can be collected.

At this point the demonstration Rabbit is no longer needed. After boiling it gently the skeleton can be well cleaned and made fit for use.

The Dog's skull must be bought. It is well to have one complete skull and one cut longitudinally.

CHAPTER XX

THE SKIN, AND ORGANS OF SPECIAL SENSE

COVERING, binding, and protecting the whole of the body is the skin, a tissue composed of many layers of cells, that form two distinct regions. The outermost of these is the *epidermis* ; the innermost is the *dermis*.

Epidermis and Dermis.

Inequalities in the outline of the dermis are closely followed by the epidermis that overlies it. The ridges formed in this way produce the characteristic "finger-prints" which, apparently, are not alike in any two individuals.

The region where the epidermis meets the dermis is the *Malpighian layer* (Fig. 126). Its cells are living, and are constantly dividing, forming smaller, flattish cells to the outside. These smaller cells are pushed more and more to the surface, by the new cells that the Malpighian layer produces. Eventually they are nothing more than dead cells, having lost their nuclei and their protoplasm. They have thus become mere horny plates and form the corneous layer of the skin (Latin *cornu*, horn).

They may separate from the surface as scurf or they may form a very thick layer in certain parts of the body. The tips of fingers and thumbs are quite horny. The layer is very thick behind the big toe and at the heel. Except for some very fine nerve-fibres in the Malpighian layer, there are neither nerves nor blood-vessels in the epidermis. No blood flows and no pain is felt when the hard layers of heel and toe are cut.

Hairs and nails, claws, scales and feathers also, are special modifications of this horny layer of the skin. Although their origin is epidermal, they appear, in section, to arise from the dermis, because there has been a pushing downward of the epidermis wherever they originate.

Hairs.

A hair is a solid, multicellular structure, whose base rests in a sac or *follicle*. In a wine-bottle the bottom of the bottle is pushed upwards into its centre. This may serve as a rough illustration of the way in which the dermis pushes up into the *hair follicle* to form the *hair-*

papilla (Fig. 126). The papilla contains blood-vessels and nerves, because the dermis, unlike the epidermis, is richly supplied with these. They provide nourishment for the hair-follicle and the hair grows by repeated cell-division at the base. The cells that are cut off die and are pushed outwards. In this way a whole chain of dead cells is formed and this chain is the hair.

The colour of hair depends upon pigment in the cells. Certain changes, usually depending upon age, interfere with the arrangement of the cells of the hair, so that they become separated by very minute air-spaces. The greyness of hair is, apparently, due to this cause.

If a hair-papilla is destroyed, as in electrolysis, no further growth is possible, and the hair drops out. A *sebaceous gland* opens into the follicle, secreting an oily fluid. The greasiness of our hair depends upon the secretion of these glands. They are also responsible for the waterproof quality of the hair of such animals as the cat, dog, and rabbit. It is because of the individual smell of this secretion that a dog recognises his master merely by sniffing.

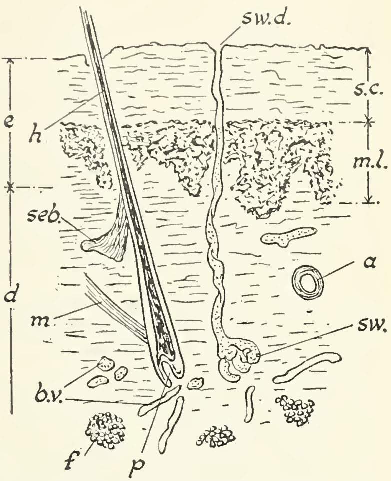


FIG. 126.—Section of human skin as seen under a microscope. *a.*, artery ; *b.v.*, veins ; *d.*, dermis ; *e.*, epidermis ; *f.*, subcutaneous fat ; *h.*, hair ; *m.*, muscles ; *m.l.*, Malpighian layer ; *p.*, hair papilla ; *s.c.*, horny layer of epidermis ; *seb.*, sebaceous gland ; *sw.*, sweat gland ; *sw.d.*, duct of sweat gland.

In nails, that part which we call the " quick " of the nail corresponds to the papilla of a hair.

Generally a hair is not upright but projects from the skin at a certain angle. There are delicate muscles in connection with the hair follicle, and these, on contraction, cause the hairs to stand on end. This may happen in the reflexes of fear and cold, or even in anger (p. 191). A cat, spitting at a dog, raises her hair in a perfect ruff. In the cat, too, as in the rabbit and many other mammals, the very long whiskers have special papillar nerves, and it is to them that they owe the extremely delicate touch-perception of this region.

In a section of skin, *sweat glands* are seen deep down in the dermis, but, like the sebaceous glands and hair follicles, their origin is epidermal (Fig. 126).

The Sweat Glands.

Sweat glands are intricately coiled tubes which lead to pores on the surface of the skin by very narrow ducts which are in the form of a loose spiral. The sweat secreted by the gland is water, with certain organic compounds dissolved in it, to which the smell of sweat is due. There are also salts in solution, particularly sodium chloride (common salt), which is perceptible to the taste when the tongue is passed over the lips.

It is by means of the sweat glands that the skin performs its very important excretory function. In Man, under normal conditions, about 700 c.c. of sweat is evaporated in twenty-four hours. Even when its presence is not obvious, it can be detected by laying the hand on a polished surface, when finger-marks remain. When the production of sweat is too great for immediate evaporation, drops of perspiration accumulate upon the skin.

In addition to being one means of ridding the body of waste, sweat also serves to regulate the body temperature.

Regulation of Temperature.

This explains the inverse ratio of the excretion of the skin and the kidneys. Much less work is done by the kidneys in summer than in winter, because the sweat discharge is great. In cold winter weather, however, the activity of the sweat glands is checked, and the body gets rid of a much larger quantity of urine.

All mammals are *warm-blooded*, that is, no matter how the temperature of the environment may vary, that of the individual remains practically constant. Our normal temperature is 98·4° F.

As a result of oxidation all the tissues of the body are concerned in supplying body-heat. This would be excessive if it were not for counteracting forces which remove the surplus heat. One such counteraction is the cooling that results from evaporation of sweat from the skin. The cooling effect of evaporation is experienced when a drop of ether is put on the hand. The cold spot that is left when the ether has disappeared shows how much heat has been drawn away in the process of evaporation.

Dogs have no other sweat glands than those in the skin between their toes. That is why, when they are very hot, they pant open-mouthed. The excessive respiration removes heat by way of the lungs, and, also, evaporation is taking place from tongue and mouth.

In addition to the cooling due to sweating, the temperature of the body is also regulated by the arteries.

In hot summer weather the skin, especially of the face and neck, is often flushed. In cold weather it is often pale or bluish. This difference is due to reflex actions which affect the muscles of the walls of the arteries in the dermis. The flush is caused by relaxation of these muscles, bringing the cavity of the artery to its maximum size. As a result more blood flows along it and more heat is given off through the skin. The reflex following the cold-stimulus causes muscular contraction of the arterial walls. The reduced cavities conduct thinner streams of blood. There is, therefore, a reduced supply of blood to the skin, and, consequently, reduced exposure of the body-warmth to the external cold air abutting on it.

A sub-cutaneous layer of fat, just underneath the dermis, acts as a jacket, preventing undue loss of heat to the outside world.

Protection.

The skin thus serves to get rid of waste and to regulate body-temperature. It also has a protective function. There is no danger of bacterial infection through the skin unless this is punctured. To apply iodine to a scratch is a wise precaution, not a fussy act. Especially is this true in gardening. One species of *Tetanus bacillus* is in garden soil and, although thousands of gardeners are scratched and continue their work with impunity, it happens, every now and again, that the one-in-a-million chance has occurred, the bacillus has entered the body through the punctured skin, and the sufferer has died of lock-jaw.

Lastly, it is the skin that receives the multitudes of tactile impressions, that are the predominant sensations of our early life. The sense-organs of touch occur just below the epidermis. They are branchings, or arborisations, of nerves whose other termination is either in the brain or in the spinal cord (Fig. 117). Impressions of contact in the legs, arms, and body generally, are carried to the dorsal roots of the spinal nerves and so to the spinal cord. In the head and face region they reach the brain by way of sensory fibres of cranial nerves.

Touch.

The wide distribution of the subcutaneous arborisations explains the serious consequences that so often follow superficial burns. Although the injury is not deep, a considerable sensory area has been affected and the patient dies, not as the result of the burn, as such, but partially because of the sensory disturbance involved. There has been a "great shock to the nervous system."

The tactile impressions that are, at the same time, taste impressions are received by the so-called *taste-buds*, which occur in the papillæ of the tongue, near its tip, and in two sets of papillæ found posteriorly.

Taste.

The sense of taste and smell are so intimately connected that it is difficult to distinguish the one from the other. Many sensations commonly regarded as taste are really sensations of smell. That this is so is experienced during a bad cold, when the olfactory sensations are blunted and food "loses its taste." It is for this reason that nipping the nose tightly greatly modifies the unpleasantness of swallowing a nasty medicine.

Smell.

For the most part tactile impressions are vague and diffuse. For more exact recording more delicate receiving apparatus is essential. In the impressions of hearing and sight, therefore, the arborisation of auditory and optic nerves is confined to a special sensory area, situated in the one case in the inner ear, in the other behind the ball of the eye.

The Ear.

There are three parts to the mammalian ear. These are the external, the middle, and the inner ear. In Man the value of the *pinna*, the obvious external ear, is slight. Other animals, the Dog, Horse, and Rabbit, for instance, "prick up" their ears in response to sound, because the function of the pinna is to collect sound-waves and reflect them inwards.

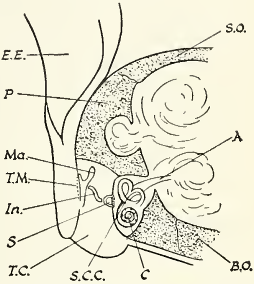


FIG. 127.—Ear of Rabbit (diagrammatic). *A.*, auditory nerve; *B.O.*, basioccipital; *C.*, cochlea; *E.E.*, external ear; *In.*, incus; *Ma.*, malleus; *P.*, periotic; *S.*, stapes; *S.C.C.*, semicircular canals; *S.O.*, supraoccipital; *T.C.*, tympanic cavity (drum); *T.M.*, tympanic membrane.

The tube, leading inwards from the pinna, the *external auditory meatus*, is also part of the external ear. In Man this is about 1 inch in length. It is supplied with glands which secrete the oily substance we speak of as "wax." The external auditory meatus leads to the *tympanic membrane*. The oily, glandular secretion keeps this membrane lubricated, so that it does not stiffen, but is able to vary its position slightly, becoming more or less concave to the exterior, as the case may be.

The *middle ear* is essentially an air-containing cavity (Fig. 127).

The Ear Drum.

The cavity lies within the bulla (p. 217) and is separated from the external auditory meatus by the tightly stretched *tympanic membrane* (Fig. 127). The cavity is the ear drum, or *tympanum*. The tympanic membrane corresponds to the stretched parchment of the orchestral drum, that is beaten to bring about, within the drum, air movement that is translated into sound.

Opposite the tympanic membrane a gap in the wall of the drum is closed by a thin layer of cartilage. This is the oval window, or *fenestra ovalis*, and its area is very much less than that of the drum membrane.

There must be some means of varying the air-pressure within the drum, to meet the variation on the outer side of the tympanic membrane. This equalisation of pressure is provided for by the *Eustachian tube*, which leads from the drum, downwards and inwards, to open at the back of the pharynx, near the internal openings of the nostrils.

The Eustachian Tube.

Normally the Eustachian tube is closed. The act of swallowing opens it. To determine its position in ourselves it is only necessary to swallow, then immediately close the external nostrils with finger and thumb and blow hard down the nose. The air is felt surging up the Eustachian tube and the drum membranes of the ears are pressed outwards as though they would burst.

The Auditory Ossicles.

Across the air cavity of the drum a chain of three little bones extends (Fig. 127). Their fanciful names indicate their shape. The *malleus* is a hammer-shaped bone whose shaft part is attached to the tympanic membrane. Its rounded head articulates with the groove of the anvil-shaped *incus*. A short process of the incus is attached by a ligament to the wall of the tympanic cavity, while a long limb crosses the cavity to articulate with the stirrup-shaped *stapes*. This is joined by a membrane to the margin of the fenestra ovalis.

The parts of the ear so far described are more or less accessory. In Birds and Reptiles there is no pinna ; an opening in the skin leads to the drum. In the Frog the tympanic membrane is flush with the surface of the skin and is seen as a darker patch behind the eye ; also one bone only passes across the drum cavity, replacing the chain of bones of higher animals. In Fishes all the parts so far described are wanting.

It is in the *inner ear* that the essential organs of hearing are found.

The Inner Ear.

The very complex inner ear lies in the periotic bone which is, in an external view of the skull, overshadowed by the bulla (Fig. 125, E). The inner ear is a many-chambered structure whose cavities are full of a fluid called *endolymph*. It lies in a bath of a surrounding fluid, the *perilymph*, which keeps it from coming into contact with the periotic bone in which it lies. Because of its complexity the inner ear has been given the name of the *membraneous labyrinth.*

The Utriculus. The two largest cavities of the inner ear are the *utriculus* and the *sacculus.* From the utriculus three small *semicircular canals* branch out. One of these lies flat to the head and is the *horizontal canal.* The other two rise vertically and are almost at right angles both to the horizontal canal and to each other. These are the two *vertical canals.*

One end of each canal swells, forming an *ampulla*, in which nerve-fibres of the eighth (auditory) nerve are distributed (Fig. 127). Similar nerve-processes occur in the utriculus, and among them lie tiny particles of a chalky substance.

The Sacculus. The utriculus opens into another cavity, the *sacculus*, and from this projects a long, spirally coiled tube, the *cochlea.*

Hearing. In the perception of sound, the sound waves strike the tympanic membrane, so that air-vibrations are set up within the drum. A movement of the chain of bones, the *auditory ossicles*, is thereby caused. As they are attached to the fenestra ovalis, this is shaken and the air vibrations are thus transmitted to the inner ear. As a result, oscillations are started in the perilymph. These waves in the perilymph cause corresponding vibrations in the endolymph of the membraneous labyrinth. The various endings of the auditory nerve are affected and, along the nerve, sound impressions are carried to the brain.

Many theories of hearing have been put forward. The one most generally accepted is a modification of the Helmholtz Piano Theory. When the top or front of a piano is removed to expose the strings, some of these vibrate when certain notes are sung. In the cochlea of the ear an extremely delicate, spirally coiled ribbon is attached along one edge. It is made up of about 24,000 elastic fibres, which gradually decrease in length. The piano theory states that as a result of air-vibrations, or waves, each fibre responds to a certain tone, the longer fibres vibrating to the lower notes.

The cochlea is very poorly developed in the Frog, and it is not present, in any form, in any animal below the Frog in development. Its complexity increases with the higher development of the animal, until it reaches its maximum in Man.

Because of the bony protective covering it is difficult to make a dissection to show the middle and inner ear. In a Rabbit's skull it often happens that the occipital ring has fallen away. Then, by peering into the skull, the auditory ossicles may be seen within the bulla. The easiest dissection to make to demonstrate the semicircular canals is in fishes. Cod's heads are often given away by fishmongers or are sold for a nominal sum. Unfortunately the Cod is a bony fish and the dissection is not so easy as in the cartilaginous Dogfish. If the hinder end of the skull is cleared of skin, just a little way back from the eye, the auditory capsule is exposed and two prominent ridges are seen. A careful paring away of the cartilage of the ridges, with a sharp scalpel, exposes the three semicircular canals, which are well developed. They are actually smaller in ourselves ; therefore, in proportion to the size of the animal, they are much larger in Fishes than in Man. Calcareous particles, or *otoliths*, occur in the auditory organ ; in fishes they are often large flat plates.

Balance.

It is the cochlea of the internal ear that receives the sensation of sound. The semicircular canals and the utriculus regulate the balance of the body. It appears that when the head is moved the otoliths in the utriculus change their position and exert pressure upon different cells. In this way different nerves are stimulated and different *position sensations* result. If a person spins round rapidly a number of times, then stops suddenly, a feeling of giddiness and of spinning in the opposite direction is experienced. The room " goes round." This feeling may persist for half a minute because, during this time, the fluid in the semicircular canals is, apparently, continuing to spin, although the head itself is still.

The Eye.

Certain differences, chiefly concerned with focusing, occur in the eyes of fishes and mammals. But as their attachment in the socket, or *orbit*, is the same, the head of a fish is a good object in which to study the insertion of a Vertebrate's eye.

When the skin has been removed from the surface of the head and cut away round the eye, it is easy to pass the handle of a scalpel between the back of the eye and the bony socket in which it lies, and so press the eyeball forward. The eye is attached by a short, thick stalk, really a part of the brain itself, but always named the optic nerve.

The Eye Muscles.

Six flat straps are more obvious than the optic nerve. These are the muscles which bring about the movement of the eye in the socket. We, as a result of this muscular activity, are able to look up or down, to the right or to the left, without moving the head.

The eye muscles are arranged in three pairs: two pairs of *rectus* muscles and one pair of *oblique* (Fig. 128).

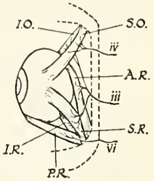


FIG. 128.—Muscles of the eye (diagrammatic). *A.R.*, Anterior rectus (internal rectus); *I.O.*, Inferior oblique; *I.R.*, inferior rectus; *P.R.*, Posterior rectus (external rectus); *S.R.*, Superior rectus; *S.O.*, Superior oblique. iii, iv, vi, oculo-motor nerves.

The two oblique muscles pass from the front of the socket, where they are close together, to meet the dorsal and ventral surfaces of the eyeball. They are called, respectively, the *superior* and *inferior oblique* muscles. They are innervated by the fourth cranial nerve and by a branch of the third.

The *superior* and *inferior rectus* muscles are just as obviously a pair as the obliques. They arise in the posterior part of the orbit and, passing forward, are attached, one above, and one below, the eyeball.

The origin of the *internal* and *external rectus* muscles (*anterior* and *posterior* in Man) is also in the back of the orbit. The internal rectus meets the eyeball near the attachment of the obliques. The external rectus is inserted on its posterior surface. It is innervated by the sixth cranial nerve.

The third nerve supplies the other rectus muscles. If it does not function properly the eye squints outwards. An internal squint results from paralysis of the sixth nerve that supplies the external rectus.

The Structure of the Eye.

For the study of the mammalian eye nothing is better than the large eye of an Ox. It has, too, the advantage of being easily obtainable and cheap.

The Sclerotic.

The eye is a globular, hollow structure, bounded by a three-layered wall. The outermost layer, the *sclerotic*, is tough and protective (Fig. 129). It is the "white" of the eye. When the finger is passed over the closed eye, a bulge is felt on the front of the ball. It is through this bulging part that light passes. In this region, therefore, the thick, opaque sclerotic is continued as a transparent layer, the *cornea*.

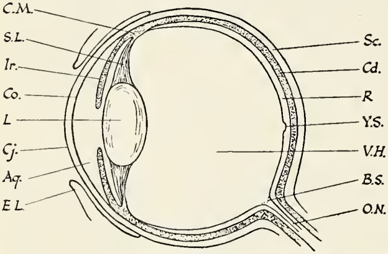


Fig. 129.—Diagram of the eye. *Aq.*, aqueous chamber; *B.S.*, blind spot; *Cd.*, choroid; *Cj.*, conjunctiva; *C.M.*, ciliary muscle; *Co.*, cornea; *E.L.*, eyelid; *Ir.*, iris; *L.*, lens; *O.N.*, optic nerve; *R.*, retina; *Sc.*, sclerotic; *S.L.*, suspensory ligament; *V.H.*, vitreous humour; *Y.S.*, yellow spot.

The Choroid.

Underlying the sclerotic is the *choroid*, which is well supplied with blood-vessels. Its innermost layer of cells, that is, the layer towards the hollow of the eye and away from the sclerotic, contains a dark pigment. This, like the black lining of a camera, prevents light that has once entered from being reflected outwards. The choroid is not a complete coat. Naturally, it is missing in front of the eyeball.

It is, however, an extension of the choroid in this region that forms the circular muscular ring of the *iris*, whose action is imitated in the diaphragm of a camera.

The *pupil* of the eye is not an actual structure, but merely an opening in the middle of the iris (Fig. 129). It gets its name from the Latin *pupilla*, a little girl, because of the little reflected figure seen when it is looked into.

The *lens* of the eye is swung behind the iris, blocking the hole, or pupil. It is supported by an enclosing sheet of tissue which attaches it to the choroid coat and is called the *suspensory ligament*. At the point of attachment of the ligament, *ciliary muscles* pass from the choroid coat to the sclerotic.

The Lens.

The lens acts as a partition, dividing the hollow eyeball into two chambers of unequal size.

The small anterior chamber, between lens and cornea, contains a watery fluid, the *aqueous humour*. The large chamber behind the lens holds the *vitreous humour*, which, as its name implies, is of a rather glassy or gelatinous nature.

The Retina.

The vitreous humour is in contact with the *retina*, the innermost lining of the wall of the eyeball, and the actual sensory region (Fig. 129). Like the choroid, it is somewhat cup-shaped, because it is not continued across the front of the eye.

Although vision, that is, the actual registering of images, is still very imperfectly understood, the mechanism of the obvious parts of the eye is clear.

The Mechanism of Sight.

The retina is the part of the eye designed to receive the waves of light. The lens is concerned in directing and focusing these rays upon it. In the mammalian eye the focusing depends upon the ciliary muscles. The lens itself is somewhat elastic, and when the enclosing tissue in which it lies, the sensory ligament, loosens a little, the lens takes advantage of the extra space provided and becomes more convex. This change is controlled by the contraction of the ciliary muscles, and it is in this way that the lens is brought into the right shape for focusing near objects on the retina.

In cases of failing sight, the eye is not focusing properly because the lens is not becoming sufficiently convex. Spectacles with convex lenses are therefore worn for close work, such as reading, sewing, or dissecting.

In using a camera the focus is changed by racking the lens backwards or forwards, according to the scale marked at the side. In the Bony Fishes there is a similar mechanism. The lens of the eye, instead of varying its convexity in focusing, does actually move backwards and forwards a little in the cavity of the eyeball.

It is the work of the iris to improve the definition of near objects and to regulate the amount of light entering the eye.

The Iris.

This it does by a contraction of the ciliary muscles, so that the aperture of the pupil is lessened. A sharper image is then thrown on the retina, and it is thus serving the same function as the " stops " of the camera. In strong light the same muscular contraction is induced. The reflex is otherwise when the light is faint, for then the ciliary muscles relax and the pupil aperture is at its widest.

It is on the iris, too, that the colour of the eye depends. Some of its cells contain black pigment. These are the more crowded in strong light to modify its intensity. Here lies the explanation of the dark eyes of Southern races. In the more sombre countries of the North as much light as possible must enter the eye. There are few pigment cells in the iris, and the typical Northerner is blue-eyed.

The aqueous humour of the small outer chamber serves to nourish those parts of the eye that have no blood-vessels—the lens, for instance, and part of the cornea. It is constantly being renewed by a process of secretion, because it escapes through the pupil into the wall of the eyeball.

Unlike the aqueous humour, the vitreous humour cannot be renewed.

The ultimate branches of the optic nerve are distributed in the retina as cells of two forms. These are the *rods* and the *cones*. Fibres from all these cells meet at the back of the eye and unite to form the optic nerve. This, in some way, conveys the image from the sensitive surface of the retina to the centre of consciousness in the brain.

Sight.

That part of the wall of the eyeball where the optic nerve pushes through, is known as the *blind spot* (Fig. 129). Here rods and cones are absent and no image can be registered.

On the retina, exactly opposite the centre of the pupil, there is a spot where the retinal layer is thinner and therefore slightly yellowish. At this *yellow spot* cones are more abundant than rods, and the sharpest definition of an image falls on this spot (Fig. 129).

Rods and Cones.

It is probable that the rods and cones carry out different functions. In nocturnal animals, such as Owls, rods are much more numerous than cones. Other birds, that roost at sundown, have very little experience of dim light or darkness, and in their retinas cones predominate.

Everyone knows the danger of matching colours by artificial light. It is suggested that in the bright daylight we judge colour by cones alone ; but that in the less intense artificial light the rods also take part in the process.

Colour.

We know that colours are seen by us because light of different wave-lengths is received by the retina. Most of us are able to distinguish the seven primary colours of the solar spectrum. Certain phenomena of colour contrast are interesting. If the eyes are first fixed on a coloured design, then moved so that they rest on a self-coloured surface, the design is seen there as an *after-image* ; not, however, in the colours of the original, but in the complementary colours. Red and green are complementary. So are blue and yellow. This principle was made use of in the old advertisement of Pears' Soap, when the gaze was transferred to the ceiling from the coloured design in the advertisement pages of the magazine.

Such an image as this is *negative*. A *positive after-image* results from gazing at a bright light. If the eyes are closed after looking fixedly at an electric light bulb, the brightness of the filament is still seen. If, after looking at the sun, the gaze is transferred to a leafy tree, myriads of little suns are seen in the deep shadows between the leaves.

Colour blindness is probably due to some abnormality in the retinal cones. To persons who are totally colour blind the whole outside world appears in neutral tints, like a photograph. This, fortunately, is very rare.

Partial colour blindness is more common—it is commoner among the male than the female population. Probably about 4 per cent. of the human male population are partially colour blind, while not more than 1 per cent. of females suffer from this defect.

As the front of the eye is a transparent window, it is essential that it be kept perfectly clean. For this purpose there is, on the temple side of the socket, the *lachrymal*, or *tear-gland*. It is constantly secreting, and the moving eyelids act as wash-leathers, in distributing the liquid and removing dusty particles. The secretion of the tear-gland becomes excessive and obvious in laughing, crying, or coughing. The liquid passes across the eye to the opposite corner and escapes by two minute holes which lead into the nostrils. This explains the running of the nose that accompanies crying.

Tears.

On the eyelids themselves there are protective lashes which help to exclude foreign bodies. Among the lashes of both lids there are little glands whose secretion hardens on contact with air. It is often found as " sleep in the eye " when one awakens in the morning. A sty forms on the lid when there is a blocking, preventing the escape of the secretion from one of these glands.

The Eyelids.

The epidermal layer on the underside of the eyelids follows the course of the lids to well within the boundary of the orbit. It is then reflected backwards over the eyeball, where it is called the *conjunctiva* (Fig. 129). A bloodshot eye is due to very swollen blood-vessels, or to burst capillaries, in this fine tissue-layer. In our young days we have all experienced the extreme discomfort of getting soap in our eyes when we were being washed. Fresh water has almost the same effect as an alkaline solution on the conjunctiva, but salt tears are in no way irritating to this delicate membrane. Neither in sea-bathing is there any inconvenience. In certain cases of eye trouble a saline wash, approximating to the salinity of tears, is prescribed because it is definitely soothing to the conjunctiva.

The Conjunctiva.

In the Rabbit, and many other Vertebrates, a third eyelid stretches across the eye from the nasal corner. In the Rabbit used for dissecting it may be held with forceps and drawn gently across the eyeball. It is constantly being shot across the eye by birds. Cats, sometimes, when they leave the dimmer light of the

The Nictitating Membrane.

house for the bright sunlight of the garden, protect themselves from its intensity by partially screening the eyeball with this nictitating membrane. In ourselves it persists, as a fixed little lump, in the nasal corner of the eye.

We all know, either by experience or hearsay, that Cats, Dogs, and "Tiger, Tiger, burning bright," have eyes that glow in the dark. This is due to a thin layer of metallic substance, interposed between choroid and retina, which acts like the metallic reflector at the back of a reading- or car-lamp. When your dog approaches you in the dark and there is a motor-car or a street-lamp near by, the light of the lamp is so reflected from the dog's eyes that they appear to be lighted up within.

SECTION IV

THE GENERAL MORPHOLOGY AND PHYSIOLOGY OF THE FLOWERING PLANT

In the life of any plant, no matter how simple it may be, no matter how complex, all activities are directed towards the best possible conditions for the individual during its own lifetime and for ensuring, as far as possible, the well-being of the generation that succeeds it.

In the Flowering Plant the vegetative parts, that is, the root, stem, and leaves, are particularly concerned with the former aim. The latter depends, in great measure, upon the flower (Fig. 130).

When it is realised that a stem is that part of the plant that bears leaves and, conversely, a leaf is that part of a plant that grows on a stem, then it is fairly obvious that a flower is nothing more than a specialised part of the plant, made up of different kinds of leaves, which grow on an extremely short stem.

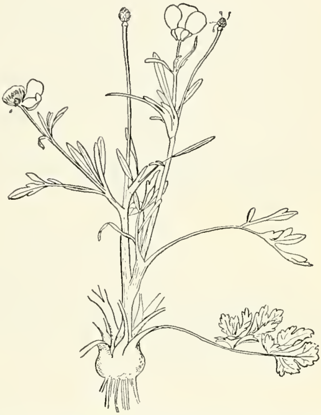


Fig. 130.—Bulbous Buttercup. The whole plant with roots, stems, leaves, flowers, and fruits.

In a typical flower there are four different kinds of leaves. These are the sepals, petals, stamens, and carpels. The production of seeds, on which the continuation of the particular species depends, is the work of stamens and carpels, and they, therefore, are the *essential* leaves of the flower. They are protected by the sepals and petals, which generally also take some part in regulating or directing the visits of insects.

The formation of seeds is followed by their dispersal. The more efficiently they are scattered, the greater is the chance of healthy lives for the plants that grow from them. As in our own human society, overcrowding is bad.

Thus the individual plant is given a fair start, more especially as there is always some provision of food as a preliminary equipment for its entry into life. When this supply is exhausted it must fend for itself. As a matter of fact, there is always enough and to spare, and the young plant is growing independently before the supply has given out.

The independence of the individual is gained by the co-ordination of roots, stems, and leaves in obtaining raw materials for the manufacture of food ; in providing an efficient transport system to carry this, in soluble form, to parts where it is either actively needed or where it is to be stored ; in maintaining airways, so that there is adequate circulation of oxygen throughout the whole plant-body ; in getting rid of waste material and, finally, in reacting in such a manner to the outside world that, in the struggle for existence, in the fight against long odds, ultimate individual success is achieved.

PRACTICAL WORK

The Prairie Buttercup (*Ranunculus ovalis*), which flowers in early spring, is very similar to the Bulbous Buttercup (Fig. 130), and may be substituted for it. Or, Shepherd's-purse may be used for this study.

CHAPTER XXI

THE ROOT

ABSORPTION of water is the primary function of roots. The roots of land-plants, as they grow through the soil, turn their tips definitely from a dry spot in the ground to one that contains more moisture.

Absorption.

It is for this reason that a mere sprinkling of gardens in dry weather is a mistake. The roots tend to abandon their normal direction of growth and turn upwards to the wet region. Watering, therefore, except in the case of seedlings, should either be done with extreme thoroughness or left alone.

This particular *irritability* of roots (and by " irritability " is meant their *tropism*, or response to some outside stimulus) can be demonstrated by germinating seeds in gravy strainers whose base is a fairly coarse sieve (Fig. 131). On a thin layer of sawdust or coco-nut fibre, that must be kept uniformly damp, mustard or cress seeds are sprinkled. Each sieve is then placed over a beaker containing water. In three or four days the seeds are germinating. A day or two later the roots are pushing through the holes in the sieve and growing vertically downwards.

The Water Stimulus.

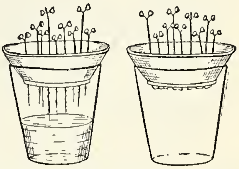


FIG. 131.—Experiment to show the response of roots to the water-stimulus.

If one sieve is now removed and put upon an empty beaker, the roots turn upwards and actually re-enter the holes of the sieve, responding to the attraction of the wet sawdust or fibre. The roots of the other set of seedlings continue their downward growth towards the water in the beaker.

This is a striking experiment to show the attraction that water has for roots and their response to this particular stimulus.

In a fully grown plant there is a certain co-ordination between the arrangement of leaves and the spread of roots, so that the former help to conduct water to the latter. For this reason a spreading tree makes a good shelter in a sharp shower. The rain that falls on

The Direction of Rainfall.

the upper part of the tree is, for the most part, conducted from the tips of the leaves of the upper branches to the branches below, which extend outwards a little farther. Likewise from the tips of these branches it drips to those immediately below, which extend outwards a little farther still. So the drip falls to the ground, following the course of a cone or pyramid, and leaves the area immediately under the crown of the tree comparatively dry.

But the branches of the roots underground stretch as far as the leaf-bearing branches overhead. Further, it is near the tips of roots that water is absorbed. Thus the steady drip from the leafy branches conducts the rain to the area where it has only to soak downwards to reach those parts of the root that absorb.

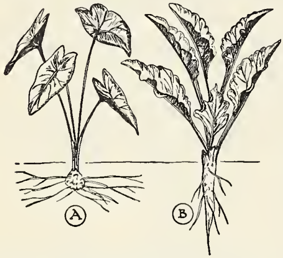


Fig. 132.—A, Plant of Arum; B, Plant of Rhubarb; showing how leaves conduct rain-water to roots. (Copied from Körner.)

This co-ordination between leaves and root is not a special feature of woody perennials, but is common, too, among herbaceous plants.

In the Arum Lily the tips of the spreading lateral roots occupy a position in the soil just underneath the tips of the smooth, shining leaves (Fig. 132). The leaf-tips bend outwards and downwards and thus conduct rain-water directly to the absorbing tips of the roots.

In Rhubarb the root grows straight down into the soil, with but few branches, and these are not spreading. The form of the leaves is such that they conduct water inwards, not outwards as in the Beech and Arum. The Rhubarb leaves are grooved on the upper surface. Water travelling down this groove continues its course along a groove of the leaf-stalk that is familiar to everyone who has peeled Rhubarb. By this route the rain is definitely conducted to the centre of the plant and soaks into the ground, just above the downwardly directed root (Fig. 132).

The same co-ordination is seen in all bulbous plants.

The upstanding leaves of Tulip, Hyacinth, and Daffodil conduct the rain to the centre, where the bulb rests just below the soil and gives off its adventitious roots.

When radical leaves grow in the form of a rosette, as in the Dandelion and many other plants, rain is also centripetally conducted by the grooved, upper surfaces of the leaves. It soaks into the soil just where the long, straight root grows downwards.

The gardener's root-pruning of Apple and other trees helps to maintain the right relation between the pruned branches overhead and the spread of the roots in the soil.

Root-hairs.

It is, generally speaking, only the region near the tip that is the absorbing area of a root. The absorption depends very largely upon numbers of fine *root-hairs* that grow in this region. It is useless to look for them on an uprooted plant, for various reasons: they have been destroyed by the pull; they are hidden by the clinging particles of soil; they have shrivelled in the dry air.

They can, however, be seen on the seedlings in the gravy strainers or, better still, on young bean roots grown in a damp atmosphere (Fig. 229). Clean gas-jars, each containing a single roll of clean blotting-paper, make excellent apparatus for the demonstration of root-hairs. Not more than two soaked Broad Beans should be slipped between the dry blotting-paper and the glass in each jar, one on either side. It is neater so to arrange the seed that the black mark, or hilum, of the coat is downwards. Water, not more than an inch or two in depth, should then be put into the jar. When the seed germinates, its root is in a damp atmosphere, and this is exactly the right environment to induce the growth of root-hairs.

It is to promote the rapid growth of root-hairs that plants must be watered freely when they have been transplanted. The uprooted plant has lost its root-hairs. In the damp atmosphere of a well-watered patch of soil new root-hairs are produced. These at once begin their work of absorption and the drooping stems and leaves revive.

The plants produce no hairs on any part of the root that is actually in water. It is only in two or three exceptional cases that they are present on the roots of water-plants. Water-plants take in water through the outermost tissue of the absorbing region of young roots.

The number of root-hairs varies greatly on different roots and under different conditions of humidity. The variation ranges from the zero of water plants to as many as 400 to the square millimetre on roots of Indian Corn grown in a moist chamber. This number has actually been counted !

One great advantage of the presence of root-hairs is, undoubtedly, the great increase that they give in the absorbing area of the root. It is estimated that in some cases the area of absorption is increased as much as eighteen times, by the presence of root-hairs.

A greatly increased area of absorption is gained by some roots because of their close association with certain fungi. In such cases the roots are closely invested by some of the exceedingly fine fungal threads, while other threads spread outwards in the humus of the soil, and absorb food compounds. Such a fungal investment is a *mycorrhiza*. Beech and Heather have adopted this method of absorption from the soil.

It is difficult to demonstrate absorption in the root-hairs themselves. It is necessary, therefore, to have recourse to analogy to make the process clear.

Osmosis.

In the physical process of *osmosis* two liquids, of different density, separated by a permeable membrane, exercise a mutual attraction for one another so that each passes, in the reverse direction, through the separating membrane.

In the laboratory, to make the experiment as striking as possible, it is well to use substances of widely different strength : golden syrup, for instance, and water.

A piece of parchment, or pig's bladder, should be tied very tightly over the mouth of the bulb of a thistle funnel, and the bulb then exactly filled with syrup. This process needs care. In pouring the syrup the tube should be held in a sloping position, so that the air in the funnel may escape along the upper side of the tube as the syrup glides down the lower side.

The thistle funnel is then clamped with the bulb suspended in a beaker of water (Fig. 133). In a very short time a rise is noticed in the level of the liquid in the bulb. The rise continues up the tube to such an extent that, if it is wished to continue the experiment, a second glass tube must be attached, by means of rubber tubing, to the end of the thistle funnel stem.

Obviously water has passed inwards through the permeable membrane. At the same time, however, the water in the beaker has become a little sweet. It is only necessary to taste it to prove this. There has, therefore, been an outward flow of syrup through the membrane. That is, *exosmosis*, as well as *endosmosis*, has taken place.

This experiment can be varied by using other solutions: a solution of salt, for instance, or of copper sulphate. Also the stronger solution may be in the beaker and the weaker in the funnel. No matter what the arrangement, there is an interchange of liquids through the membrane.

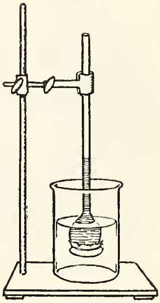


Fig. 133.—Experiment to show osmosis.

Osmosis in Living Cells.

This process has taken place in apparatus made up of non-living parts. It is easy to prove that it can take place, to some extent at any rate, in living cells.

With the exception of the outside skin, a potato is completely made up of living cells. For this reason, and because of its bulk, it makes a good piece of apparatus for demonstrating osmosis in living tissue.

In order to have a control experiment two large potatoes are used. Each has a piece cut off one end, so that it may stand on a flat base. Above the base a ring of skin is peeled away. A pit is made in the middle of each potato, stopping short within an inch of the base. They are now put into separate dishes, so that each stands in an inch or so of water. One pit has a little sugar put into it; the other is left empty (Fig. 134).

The sugar dissolves in escaped moisture and forms a solution at the bottom of the pit. Very soon a rise in level is noticed here, as in the glass tube of the thistle funnel. Attracted by the sugar solution, water has passed from the cells that form the sides of the pit. Owing to loss of water the cell-sap in these particular cells becomes stronger than it is in neighbouring cells beyond these. This stronger cell-sap now attracts water from neighbouring cells beyond them, so that they, in their turn, contain a stronger sap than the cells immediately beyond them. So a chain is started which ultimately affects the cells quite on the outside of the potato, and they attract the water of the vessel in which it stands. It was to allow this water to enter that a little of the potato skin was peeled away, because the cork layer of the skin would otherwise hinder the entrance of water.

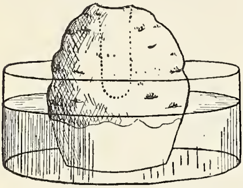


FIG. 134.—Experiment to demonstrate osmosis in living cells.

There is, then, a gradual rise of liquid in the pit of the potato, because osmosis has taken place through its living cells. In the control experiment there has been no such rise; the pit is completely dry.

Another very striking experiment may be carried out with a cube cut from the middle of a fresh beetroot. The red sap that oozes from the cut cells should be removed by washing in tap water. When the cube is now dropped into a beaker of cold water there is no outward flow of red sap.

Osmosis under the Control of Protoplasm.

If the same cube is killed by being dropped into boiling water, then transferred once more to the beaker of cold water, the red sap flows out freely. This proves, beyond all doubt, that there is something present in the living cells that keeps them from losing their solutions.

This " something " is the primordial utricle, a layer of protoplasm that lines the cellulose wall of each young cell and, by its action, modifies osmosis (Fig. 10).

It is upon osmosis, modified by living protoplasm, that the absorbing capacity of root-hairs depends.

A root-hair is one cell of the outermost tissue of a young root. The tissue is called the *piliferous layer*, because it produces the "pile," or hairs. Each hair is formed by the outside wall of a cell growing out for some distance, at one point only. The cell-sap within the hair is a slightly acid mineral solution, but, as it is stronger than the mineral solutions in the surrounding soil, these are attracted through the cell-wall and enter the cell.

Roughly, then, the root-hair cell corresponds to the thistle funnel with syrup, and the soil and its mineral solutions are represented by the beaker and water.

The difference in the osmotic process in the two cases depends upon the living protoplasm. The cellulose wall and the primordial utricle lining it, together form a *semi*-permeable membrane. The result is that while there is a very definite *endo*smotic current, only a very small proportion of the contents of the cell is allowed to escape outwards, into the soil.

Through neglect a potted plant may droop so much that it appears almost lifeless. Unless the neglect has been too gross the plant invariably recovers on watering, especially if tepid water is used, because roots absorb warm water more readily than cold. Endosmosis takes place more quickly under these conditions, the individual cells become entirely filled with water, and the drooping leaves of the plant are restored to their normal turgidity.

In England, in winter, a window plant sometimes suffers because it is "caught by the frost." The droop of its leaves is much like the similar state in a neglected plant. In this case, however, no watering restores the freshness and turgidity of the leaves. The frost has killed the primordial utricle of the living cells. Under such conditions the cells can never become turgid.

Were it not, then, for the intervention of the primordial utricle, there would be no such thing as turgidity in plants. But the growth of cells depends upon the preliminary stretching of their walls due to their turgidity (p. 20); therefore if there were no turgidity there would be no growth. We come, then, to this logical conclusion: *In the absence of control by the protoplasm of young cells, life, as we know it, at any rate, would cease to exist.*

The Passage of the Absorbed Solutions.

It is not enough for water, with mineral substances in solution, merely to enter the root-hair. As far as the plant is concerned its journey is only now begun. A chain of progress is started, exactly as in the potato that holds a solution of sugar. The cell-sap in the root-hairs becomes weaker as a result of this absorption of weak solutions from the soil. The sap of a neighbouring cell, towards the interior of the root, is therefore stronger than this. Thus solutions originally absorbed by the root-hair travel, as a result of the osmotic force thus set up, to the inner region of the root. Here they enter the vessels of the wood, but not as a result of osmosis because the vessels are dead elements. The solutions are in some way forced into their cavities as a result of pressure. Having entered one vessel, the absorbed solutions can pass to others through thin places in the vessel walls. In these vessels of the wood the sap then rises. Exactly how it does so is one of the many unanswered problems of science.

The Selective Power of Protoplasm.

Protoplasm in some way exercises a selective power of absorption and allows certain substances to enter the root-hairs more freely than others. Those that the plant makes use of are quickly removed from the root-hairs, which then absorb still more of these particular substances. It is on this fact that the *rotation of crops* depends. Hundreds of years before there was a Science of Botany, agriculturalists refrained from growing the same crop on the same land two years in succession. By varying the crops better results were gained. The scientific reason for this is that one crop, X, let us say, absorbs certain substances, ABC, in excess and so impoverishes the ground as far as these particular substances are concerned. Another crop, Y, requires but little of ABC but absorbs other substances much more freely. During Y's tenure of the soil, therefore, the substances ABC are gradually re-accumulating, with the result that, after a certain interval of time, if the crop X be grown once more on this plot of land, ABC are again present in sufficient proportion to supply its need (p. 438).

In different parts of the country slightly different rotations are in practice. A four-year cycle is common in the Eastern Counties of England. Clover is followed by Wheat; Turnips or some other root crop follow; and in the fourth year Oats or Barley are harvested.

Rotation of Crops.

This is the Norfolk Rotation. If every fourth year is not assigned to Clover, some other Leguminous crop takes its place. The Clover is harvested for fodder, but the roots are ploughed into the soil, thereby greatly increasing its nitrate content.

This increase depends upon the association of the roots with bacteria; a partnership somewhat analogous to that of Beech and Heather with the mycorrhiza-forming fungus.

Root Tubercles.

The bacteria enter Leguminous roots from the soil by way of root-hairs. In the cortex of the root they multiply rapidly. To accommodate the colonies of bacteria, the tissues of the roots grow in such a way that *nodules*, or *tubercles*, are formed in numbers along the main root and its branches (Fig. 231).

These nodules occur on the roots of very many Leguminous plants that grow in the earth. They are not present on the Broad Bean roots in the experimental gas-jars, because the invading bacteria are absent from the water.

The enriching of the land depends upon the power of these particular bacteria to make the free nitrogen of the air in the soil combine with other elements, so that ultimately nitrates are abundantly formed. Their mode of action is by no means understood, but the result of their activity has been demonstrated repeatedly. Soil in which Alfalfa or Clover has grown has been found, upon analysis, to be richer in nitrogen at the end of the growth period than it was at the beginning, in spite of the fact that the roots have been absorbing nitrates during the whole period.

In spite of the intervention of the primordial utricle there is, as a matter of fact, some slight exosmosis from root-hairs. In other words, some of the acid of the cell passes out into the soil. By means of this acid certain substances in the soil, which are insoluble in water, are brought into solution and so made available for absorption by the root.

The Acid Reaction of Roots.

By using blue litmus solution the proof of this is simply and strikingly obtained. The solution should be in two test-tubes, one of which is to serve as a control. Into the other tube the roots of a plant dip. A tuft of Sweet Alyssum or a Broad Bean seedling acts excellently. It is not long before the litmus solution surrounding the root changes colour. On comparing it with the control, it is seen to be decidedly pink, proving, beyond doubt, that acid has entered the litmus solution from the root.

Comparison of Rate of Absorption.

The rate at which roots absorb water under different conditions may be measured by transferring a strongly growing plant to a gas-jar containing water. A Fuchsia, because of its strong stem, is excellent for the purpose.

A wedge-shaped portion is cut out of a well-fitting cork. In the remaining part two holes are bored for the passage of a thistle funnel and a glass tube bent at right angles, whose short arm is the depth of the cork into which it fits. From the tip of the wedge the smallest piece possible is cut off to give room for the Fuchsia stem. The divided cork, with its equipment, is then fitted into the gas-jar, which is full of water (Fig. 135).

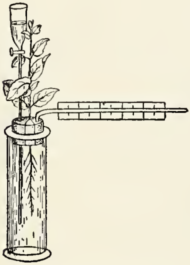


Fig. 135.—Experiment to compare variations in the rate of root-absorption.

Unfortunately there are a great many connections to make air-tight, and unless the apparatus is absolutely air-tight it is useless. The most satisfactory means of attaining this result is to mould and press just-melted, or just-solidifying, paraffin wax into all the junctions, between the cork and the glass, and the cork and the stem, particularly, but also all over the cork, because it is porous. It is a tedious process, and it is unlikely that the first attempt will be successful.

The thistle funnel is filled with water. When the tap is turned on water will enter the already full gas-jar and fill the long horizontal arm of the bent tube. If the apparatus is really air-tight the water will not run back along this arm when the funnel tap is turned off.

When the Fuchsia roots absorb water from the gas-jar, the loss in the jar is made good by a flow of water into it from the horizontal tube. A scale marked out in inches is attached to the tube, so that the time taken by the water in travelling backwards may be read accurately : thirteen minutes, let us say, for the first inch ; eleven minutes for the second ; twelve minutes for the third, and so on. The average time for a one-inch backward flow may then be calculated. With this as a standard the variations in rate, induced when the apparatus is put under different conditions, are noted.

If the leaves are blown with bellows, in imitation of a breeze, the water travels backwards along the tube more quickly than before, because the roots are now absorbing water at a greater rate. They also absorb more quickly if the gas-jar stands in warm water. On the other hand, the rate of absorption decreases if the gas-jar is cooled by being packed round with ice. It decreases, too, if salt solution is added through the thistle funnel.

The apparatus may be used indoors and out of doors ; in rain or in wind ; in sunlight and in shade. Under the varying conditions the rates of absorption may be accurately compared.

The actual volume of water absorbed under these different conditions may, of course, be calculated by measuring the diameter of the glass tube, for $l.\pi r^2 =$ volume.

Many theories have been put forward in an attempt to explain the rise of water in the vessels of the wood, especially in tall trees.

Root-pressure.

It has been suggested that the root acts as a pump, forcing the water upwards. Such a force can certainly be demonstrated in the root at certain times. Again a young potted Fuchsia is a good plant to use for such a demonstration, because of its sturdy stem. Tree saplings are good, but are not so readily available. The time to choose for this demonstration is the beginning of the summer term, some time in May.

The Fuchsia chosen should have one main stem, not one that branches into two just above the surface of the soil.

The whole leafy crown of the plant must be cut off, so that an inch or so of main stem projects above the soil. A long piece of glass tubing, of just the right bore to fit closely, is then at once carefully put over the projecting bit of stem. A 2-inch length of rubber tubing, previously slipped over the glass tube, is so adjusted that it completely encloses the connection between glass and stem. This joint is made air-tight by tightly binding the rubber tube at each end.

The plant-pot should stand in a saucer of water, the tube being supported by a clamp. The rise of water in the tube, due to the pumping action of the root, is fairly rapid (Fig. 136). It increases on gently warming the root or on the addition of warm water to the soil. There is also a certain periodicity in the rise ; more water is pumped up by night than by day. As the days pass the pumping action gradually slackens. In about ten days' time, if a Fuchsia has been used, it stops altogether. The stoppage in the root's work is due to a stoppage in the supply of food, because the plant is now leafless, and leaves make the food. The roots work as long as the food store they contain holds out. Once this is exhausted no further food is forthcoming, because of the absence of leaves, and the work of the root comes to an end.

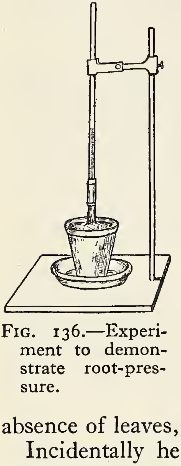


FIG. 136.—Experiment to demonstrate root-pressure.

Incidentally here is a proof that raw materials, as such, are quite useless as food. Before they can be of any service to the plant they must be worked up, in the leaves, into definite compounds which are the actual food of the plant.

Here, too, is the explanation of the fact that, in late years, so many Oak trees have been destroyed in England by the armies of caterpillars that have eaten their leaves throughout the summer and early autumn.

Later in the year root-pressure is of a negative character, because of the very active transpiration of the leaves. In early spring, when root-pressure is at its maximum, sap is seen to exude from the cut ends of many stems, as from an

Apple tree, pruned in the spring (which is the wrong time of year to choose) or from the cut stems of Vines. But if an actively transpiring plant be cut in the summer time, even quite near the root, there is no exudation of sap. The amount of water supplied by the root has not been sufficient to make good the loss due to transpiration through the leaves.

Root-pressure alone, then, cannot account for the ascent of water in high trees.

Respiration.

In such lowly animals as the Earthworm oxygen, needed in breathing, is taken in through the moist skin of the whole body. In the higher animals, the breathing apparatus becomes more and more specialised, until finally the extremely complex human mechanism is evolved. In plants, no matter what their degree of development, there is not the slightest trace of specialised respiratory organs. As in the Earthworm, so in plants both high and low, the interchange of gases in breathing takes place through the outer layers of every part.

As all output of energy depends upon intake of oxygen, there must be some supply of oxygen available for the root and a discharge of carbon dioxide from it. This latter gas, dissolving in soil-water, forms carbonic acid and, like the acid from the root-hairs, helps to bring into solution some of the mineral substances in the soil.

Unless they are liberally supplied with oxygen, roots cannot carry on their very active work. If they are unfavourably placed in the soil with regard to this gas, they die. Farmers, therefore, drain and plough land, so that air may be drawn into the soil for the use of roots. Gardeners dig with the same object.

Pyrogallic acid has the power of absorbing oxygen with great rapidity and is, therefore, a ready means of absorbing oxygen from a limited supply of air.

The Respiration of Roots.

If a bean seedling, whose root has grown about 2 inches, is suspended from the cork of a gas-jar that contains a solution of pyrogallic acid, its development is arrested (Fig. 137). Probably it will not die for some little time, because plants have a faculty, denied to animals, of making use of the oxygen of their own tissues for a limited period. This is known as *intramolecular respiration* and accounts for the lingering life of the suspended seedling (p. 393). Even so, the seedling lives only for a week or two at the longest. Its death is largely due to the fact that its root is deprived of oxygen and therefore cannot breathe. During this period a similar seedling, suspended over water, has grown freely ; the shoot has emerged and is growing upwards, while the root has elongated and given rise to lateral branches.

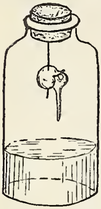


FIG. 137.—Seedling suspended over pyrogallic acid.

The imperative need of oxygen is seen in the roots of " pot-bound " plants. The main root grows downwards until it is hindered by meeting the base of the flower-pot. After this it, like the outwardly extending branch roots, grows round and round between the soil and the pot, which is porous. Through the pores a small amount of air enters and the roots are getting into as close proximity as possible with this incoming air. When a plant is in this condition its roots should be gently separated before it is transferred to a larger pot. It is well to let the plant stand for a little time in water before putting it into the new pot. Then, after the addition of the necessary extra soil, it should be well watered, so that in the damp atmosphere root-hairs may develop in the shortest possible time.

Absorption is not the sole function of roots. In all land plants one very important part of their work is to give firm

Anchorage.

anchorage. For this reason the root burrows into the ground, pushing aside the finer particles of earth, and curving round immovable objects, to resume its original direction once the obstacle is passed.

In trees the fact that the spread of the branches overhead is balanced by the spread of the roots makes for security. In all land plants the delicate root-hairs are a surprisingly important factor in giving the plant a firm grip on the soil, because of the tenacity with which they cling to the soil particles. It is difficult, in fact impossible, to divest a root, by shaking, of the particles of fibre, sawdust, or earth in which it has been growing.

This firm attachment is due to a change that takes place in the wall of the hair when it is in contact with the particles of soil. The wall becomes softened and mucilaginous, so that wall and particle are not merely in contact, but are practically fused together. It is this tenacious hold that partly explains why plants really suffer so little, comparatively speaking, in a drought. Michaelmas Daisies and Chrysanthemums flowered profusely in England in the autumn following the summer drought of 1929. Apparently they had not suffered in any way from lack of water, but they had benefited greatly from the extra sun.

Roots play yet another important part in the plant's life-history, by receiving and storing food that has been made in the leaves. The roots that we use as food contain the greatest store. The Carrot, Turnip, Beetroot, and Radish are swollen with reserve supplies (Fig. 143, A).

Storage of Food.

All these plants are *biennials*. In the first year of their growth they bear no flowers. The whole energy of the plant is concentrated upon food manufacture in the leaves. The manufactured food, in soluble form, is then carried down the stem through the tissue known as bast, or phloem, and so reaches the root for storage. The following spring the plant produces flowers as well as leaves, and fruit- and seed-formation follow. There is a great demand for food for all these rapidly growing parts. The demand is met by the supply stored in the root.

Biennials.

If at this period such swollen tap-roots are used as food, they are tasteless, tough, and stringy. The plant has made use of its own reserves, and there is nothing left for us.

As soon as the seeds are set, in the second year, the whole plant dies. Its life-history is completed.

It is not only the obviously swollen roots that hold food reserves. Possibly with the exception of roots of annuals and adventitious roots of underground stems, all roots contain a certain store. This was instanced in the power of the Fuchsia root to continue its pumping action for several days, although it was receiving no fresh supplies of food (p. 252).

In the autumn, before all the aerial parts of herbaceous perennials die down, the food manufactured by the leaves is deposited in the roots. For this reason young shoots of Delphinium, Monkshood, Snapdragon, Columbine and the like, grow up rapidly in the springtime; each has a store of food to draw upon, just as surely as the embryo of the germinating seed has its reserve supply (p. 401).

Perennials.

The Carrot, Beetroot, and the like are *swollen tap-roots*.

Tap-roots.

The ordinary *tap-root* is typically seen in a germinating Broad Bean (Fig. 229). It is a long root that grows straight down into the ground on a line with the main stem. It tapers to a point (possibly this may be the origin of the name) and bears branch roots that are shorter and finer than the main root from which they spring. But it is only in size and direction of growth that the branches differ. In structure they are the same as the parent axis, because roots, unlike stems, *only bear lateral appendages that are similar to the main root*. Hence a root does not bear leaves.

In beans that have germinated in gas-jars the secondary roots leave the main root almost at an angle of 90°. When plants produce tertiary roots they may often come off at an angle of about 45°. In the soil this arrangement may be interfered with by various obstacles, but the point to notice is, that it is only the main root that obeys the pull of gravity by growing vertically downwards.

The Root-cap.

On the main root and its branches, a short distance behind the root-tip, are the numerous white, plush-like root-hairs. With the naked eye, still better with a lens, a slight yellowish swelling is seen at each root-tip. This is the *root-cap* (Fig. 229). It fits over the root as a thimble fits over a finger. The analogy is not good, because root-tip and root-cap are intimately united.

The root-cap bears the brunt of friction as the root bores its way through the earth. Its outside layers get worn away as the root pushes on, but new inner layers are formed by actively dividing cells, and so the delicate root-tip is permanently protected.

The whole length of the root is not concerned in this onward growth. The actual region of elongation may be demonstrated by marking off equal intervals on the axis. This is done with Indian ink. A ruler is put alongside the seedling, and the marks, a millimetre apart, are very carefully made on the root with a mapping pen or a piece of cotton dipped into the ink. The accompanying drawings show the elongation, in this particular case, in a period of twenty-four hours (Fig. 138).

Region of Growth in Length.

The most active growth, as shown by the wide separation of the marks, takes place a little distance behind the root-tip. An inch and a half behind the tip growth in length has ceased, as is seen by the fact that the two intervals here have remained unchanged.

The examination of many seedlings shows that root-hairs only appear where growth in length of the root has ceased. This is good economy, for the root-hairs cling firmly to earth-particles, and if they were on the growing region they would be torn away as the root pushed onwards.

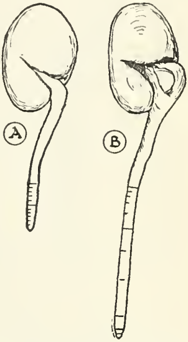


Fig. 138.—A, Bean seedling at 10.30 on Thursday. B, The same at 10.30 on Friday ($\frac{2}{3}$ natural size).

The root-hairs always occupy approximately the same position with reference to the root-tip, so it is evident that they have an ephemeral existence. As they develop on the newly added lengths of root, they die off on the older part behind.

Even to this almost universal rule there are some few exceptions. Two or three members of the Compositæ, that is, the family to which the Dandelion belongs, not only have root-hairs over their entire length, but these have a fairly permanent existence, continuing their work of absorption for two or three years.

Response to Stimulus.

The forces that influence the direction of growth of roots are moisture, gravity, and light. They grow towards moisture, towards the centre of the earth and away from light. That is, they are *positively hydrotropic* and *geotropic*, but (with qualifications) *negatively heliotropic*.

From the seedlings growing in the gas-jars one should be chosen with a straightly growing root, about an inch and a half in length, and the root marked off as before into millimetres. It must then be pinned in a horizontal position, through the seed-part, to a strip of cork which stands in a gas-jar, or better still in a larger, rectangular jar, with 2 inches or so of water at the bottom.

Responding to the double stimulus of gravity and moisture, the root makes a right-angled bend, so that the tip points directly downwards (Fig. 139). What is significant in this is, that the bend, as instanced by the divergence of the ink marks, has only taken place in the actively growing region. When the experiment is repeated with a similar seedling that has had its root-tip cut off, no bend occurs.

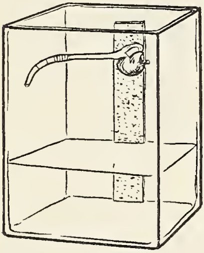


FIG. 139.—The curving of a root at the growing region.

The conclusion, then, is that the tip actually receives the stimulus and that this is transmitted by the protoplasm from cell to cell until, in the elongating region, and here only, there is active response and the bend occurs.

In some few plants it has been shown that the growing region of the root is itself sensitive to stimulus. In the Lupin the root makes the bend even when the tip has been removed.

By slipping soaked seeds in any position between blotting-paper and gas-jar the same result is seen. No matter how the seed is placed, the root grows down and the stem grows up.

A very simple way of showing the response of the root to the action of gravity alone, is to fix the root of a straightly

Geotropism.

growing bean seedling in the smallest possible hole in a cork that fits tightly into a gas-jar full of water. For the success and continuation of the experiment all connections, between root and cork, and between cork and glass, must be made absolutely water-tight by using paraffin wax.

When the plant has grown in a normal position for two or three days the jar should be turned upside down, being held by a clamp or an iron ring. If the apparatus is water-tight there will be no drip, and the plant may be left in this position for some weeks.

Inside the gas-jar the main root bends, in the growing region only, to grow vertically downwards. The branch roots take up their normal position. The stem makes a definite bend, also in the growing region, and grows vertically upwards (Fig. 140).

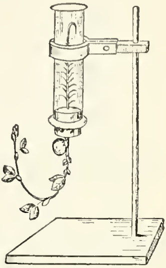


FIG. 140.—Plant inverted to show the adjustment of root and shoot.

The Klinostat.

This response to gravity may also be shown by using a klinostat, or a clock, in which the minute hand has been replaced by a firmly fixed rod, projecting outwards from the face. Damp moss must be tied very tightly to this projecting arm, so that it is sure to rotate with the arm when the clock is wound up.

Pea seedlings are then pinned, in any position, to the moss, the clock is wound up, and the whole apparatus is put under a large bell-jar, so that the seedlings are in a moist atmosphere (Fig. 141).

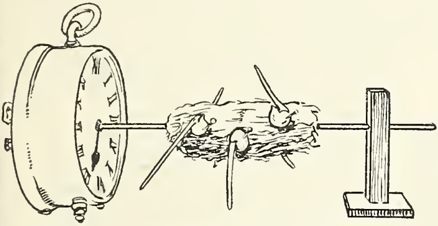


FIG. 141.—Pea seedlings on a klinostat.

The shoots and roots continue to grow in the direction that they held when first they were pinned to the moss. If root and shoot were originally horizontal, they keep this position.

This is because the force of gravity is never concentrated on the actual tip of root or stem. These are solid cylinders. No sooner does one point on the circumference of the tip respond to the attraction, than the rotation of the arm brings the next point under the influence of the gravitational pull. As this responds another turn brings yet another point into the direct range of the stimulus, and so on and so on, the ultimate result being that every point on the circumference is, in turn, equally influenced. The root and stem, consequently, grow on in their initial direction, the gravitational influence having been rendered null and void.

Heliotropism.

Heliotropism is the particular tropism, or response, that plant-organs make with reference to the stimulus of light. Main stems grow towards the light, that is, they are positively heliotropic.

The general statement that roots are negatively heliotropic needs qualification. Apparently all aerial roots are negatively heliotropic: the adventitious roots of Ivy always grow on the side of the stem that is in the shade.

Many earth roots, but certainly not all, are also negatively heliotropic. This is true of the Sunflower and of most of the members of the Cruciferæ. This response may be seen when soaked Sunflower "seeds" are allowed to germinate in coco-nut fibre in a glass-fronted box. The "seeds" are planted close up against the glass front, which faces a window with a good light. The roots grow inwards, away from the light.

If Broad Beans are used instead of Sunflowers, the roots generally grow inwards at first. Then they come to view once more. Although after this they do not actually burrow backwards into the darkness, they grow in an irregular way, as though irritated by the light.

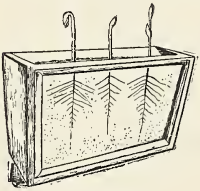


FIG. 142.

The same experiment may be repeated with black paper covering the glass front, so that all light is excluded. The root-tips are in both cases attracted backwards by the moisture; they are attracted downwards by gravity. If the box be tipped slightly forward the glass front makes a diagonal in a parallelogram of forces and the roots grow diagrammatically, closely pressed against the glass (Fig. 142). If the front is not darkened and is allowed to face the light, a deeper tilt is necessary to make the roots grow against the glass.

In the germination of seeds the root emerges from the protecting seed-coat before the shoot. It then grows down into the ground to get on with its work of absorption and anchorage.

Root Forms.

The elongation of the radicle is the tap-root, the first root-form of every plant (p. 256).

All young forest trees have a well-defined tap-root. In most cases this either dies away, sooner or later, or its growth in length is arrested and the branch roots, spreading out horizontally in all directions, form the whole root system of the plant.

In time the spreading branch roots may form considerable ridges above the soil. When they first occupied their position they were young and thin. Each succeeding year saw an increase in their girth, and as they thickened they exerted considerable pressure on the soil in which they lay. The solid ground below them was in this way pressed downwards. The lighter layer above them was raised and pushed aside, so that the roots appeared above the ground-level. Still further denudation may be caused by wind and rain, and sometimes the lower, as well as the upper, part of the root becomes exposed, and the branch root makes a sort of elongated archway a little distance above the ground.

Fibrous Roots.

In many groups of plants it is the normal thing for the first root to die away and for its place to be taken by roots that grow from the stem. This is the case in all Grasses. Roots that grow from any other part of the plant than the primary root system are called *adventitious roots*. In the Grasses the adventitious roots are threadlike. A clump of these, growing from the base of one grass-stem, is known as a *fibrous root* (Fig. 143, C).

A fibrous root, then, is one in which the primary root has died away; all the branch roots are thin and threadlike and grow from the base of the stem.

Tuberous Roots.

A third form of root is the *tuberous root*, characteristic of the Dahlia (Fig. 143, B). In this case, too, the primary root dies away and adventitious roots grow from the base of the stem. These branches are, however, extremely swollen, because of the large amount of food material they store.

Artificial Vegetative Propagation.

It is on the growth of adventitious roots that the " striking " of cuttings depends. Torn or cut stems of Roses, Geraniums, and Fuchsias, when brought into contact with damp earth, or even with water, are, in some way that is not understood, stimulated to put out adventitious roots. Poplar and Willow twigs, kept in water in the laboratory, produce numbers of such roots in a very short time.

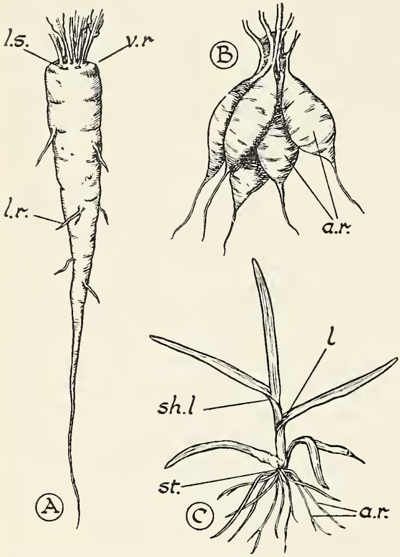


Fig. 143.—A, Swollen tap-root of Carrot. B, Tuberous root of Dahlia. C, Fibrous root of Grass (Poa annua). *a.r.*, adventitious roots; *l.*, ligule; *l.s.*, leaf scar; *l.r.*, lateral root; *sh.l.*, sheathing leaf; *st.*, stem; *v.r.*, vertical rhizome.

Begonia plants are readily obtained by tearing or cutting the leaves and pinning them closely to damp sand or soil, so that the prominent veins of the under-surface of the leaf are embedded in the soil. Adventitious roots grow out from the angles formed by the veins; a shoot grows upward at the same time and thus a new plant arises without the intervention of a seed.

Such methods of propagation are *vegetative* as opposed to *sexual* reproduction.

The generally accepted definition of a root is that it is that part of a plant that does not bear leaves; the lateral appendages resemble the axis from which they spring. This definition does not hold good in all cases.

Radical Shoots.

It is a difficult matter to keep a lawn free from Dandelions. Spudding down to a considerable depth still leaves some of the tap-root in the ground. Later a new rosette of leaves occupies the position of the old one. The root has actually formed a bud from which the leaf-rosette has grown up above the ground (Fig. 182). The explanation of this very tiresome habit may be that, after the mutilation, it is useless for branch roots to grow from the small portion of tap-root remaining in the ground, and that therefore the contained sap, designed for their production, is so diverted that leaf-buds are developed in their stead.

Such buds are termed *radical buds*, and the shoots to which they give rise are *radical shoots*. They are by no means rare, but occur alike on the roots of herbaceous plants and of shrubs. All gardeners are familiar with them as *suckers* in the Raspberry, the Lilac, and the Rose.

CHAPTER XXII

THE STEM

THE stem, unlike the root, bears lateral appendages that are different in form from the axis that produces them; that is, *the stem bears leaves.*

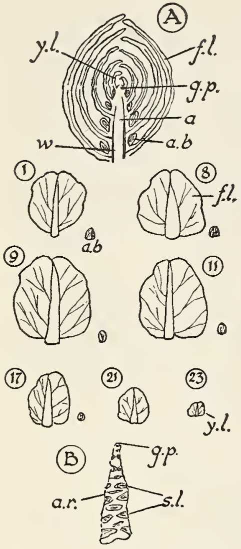


FIG. 144. — Bud structure (Brussels Sprout). A, Longitudinal section. B, Dissection, the foliage leaves being numbered in order of removal. *a.*, axis; *a.b.*, axillary bud; *f.l.*, foliage leaf; *g.p.*, growing point of axis; *a.r.*, axis remaining after dissection; *s.l.*, scars of foliage leaves; *w.*, wood vessels; *y.l.*, young leaves protecting growing point.

In the *leaf-axil*, the angle which the leaf makes with the stem, there is commonly a leaf-bud. This is a branch in miniature, a branch whose axis is extremely short and whose leaves, therefore, are very closely packed. The youngest leaves bend over the tip of the rudimentary stem and so protect the growing point.

Bud Structure.

A Brussels Sprout, which grows in the axil of a leaf of one variety of Cabbage, is so big that bud structure is very plainly seen in its longitudinal section (Fig. 144).

The basal leaves of the bud are the largest. At the tip tiny crinkled leaves curve over the growing point. In the axils of most of the leaves there are well-formed *axillary buds.* A careful dissection of one of the largest of these shows the same structural plan as that of the mother-bud.

Resting Buds.

The buds of trees have a long spell of waiting to pass through. They are formed early in the summer and do not expand until March or April of the following year.

To fit them for this resting stage they are not naked, as is the Brussels Sprout, but are enclosed in a certain number of *scale-leaves.*

The Horse Chestnut Bud.

On the outside of the bud of the Horse Chestnut there are dark, tough scale-leaves whose stickiness gives them most effective additional protection against external ills; against cold and wet, and against attacks of fungi and micro-organisms generally. At the same time the scale-leaves make it impossible for the rudimentary foliage leaves they enclose to lose water.

In dissecting this bud it is necessary, now and again, to dip both it and the dissecting needle into methylated spirit. The stickiness dissolves in the alcohol, and so the work of dissection is made easy.

For the purposes of dissection it is well to choose a *terminal bud*, that is, one that is not developed in a leaf-axil, but is a direct continuation of the branch. The scale-leaves grow in pairs on the short axis of the bud and are disposed at right angles to one another. The scales at the base of the bud are very small. The succeeding scales are increasingly larger. The last pairs are not only very large, but are completely circular, or even overlapping, so that their removal is a little difficult. When they are removed, the methylated spirit is finished with; its further use only makes the remaining leaves of the bud messy and bedraggled.

These remaining leaves are two pairs of foliage leaves, each leaf being possibly about the size of the little finger-nail. The fluffy hairs that cover them afford still further protection. When this fluff is removed the form of the foliage leaf is revealed. It is made up of slender leaflets, five, seven, or even nine in number (Fig. 145, E). Each leaflet is folded bookwise, along the middle line.

The tip of the axis of this particular bud bears a roundish mass of flower-buds that expand in the springtime into the beautiful Horse Chestnut inflorescence that stands erect, like a well-fixed candle on a Christmas tree.

If Horse Chestnut twigs are kept in water in the laboratory the buds will burst, in the warm room, some time before they expand in nature. Every detail of their opening may then be seen. The stickiness melts and the scale-leaves are pushed apart. Later they bend slowly backwards until their final position is directly opposed to their original one and the tips of the leaves point down.

In the meantime the axis has not only elongated, but it is much thicker and there has been a rapid elongation of the leaf-stalks. When these form an angle of 90°, or somewhat less, with the axis, the blade of the leaf is like a baby's hand inside the fingerless baby's glove. The blades then lose the protecting hairs and turn green in the light. The leaflets spread out in the finger-like manner that has given the name *palmate* to the compound leaf of the Horse Chestnut (Fig. 146 (4)).

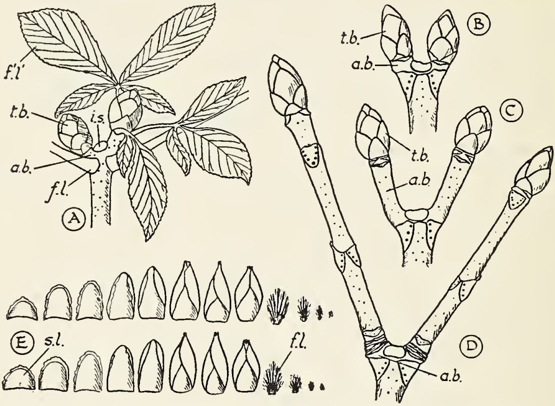


FIG. 145.—Horse Chestnut. A–D, Drawings to show branching after the formation of an inflorescence. A, A twig in autumn with short lateral branches (*a.b.*) formed in the axils of the last pair of foliage leaves (*f.l.*) $f^1.l^1$. foliage leaves borne on the short lateral branches; *t.b.*, terminal buds of the lateral branches; *i.s.* scar of recently fallen fruit axis. B, Similar twig in late autumn. C, Similar development to that shown in B, but with longer stems formed from the naked lateral buds. D, Twig B a year later. E, Dissection of a bud. *s.l.*, scale-leaves; *f.l.*, foliage leaves.

While the foliage leaves have been expanding in this way,

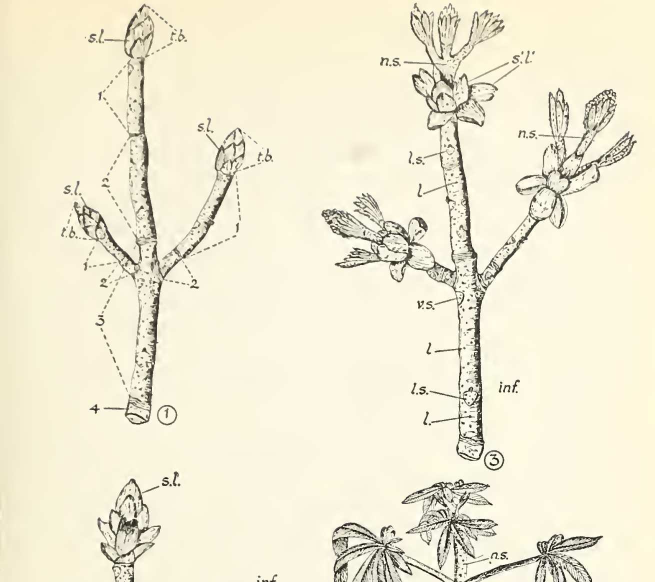


FIG. 146.—Successive stages in opening Horse Chestnut buds. 1 Last year's growth of stem; 2 growth of stem last year but one; 3 stem that grew three years ago; 4 stem that grew four years ago; *a.b.*, axillary bud (dormant); *f.l.*, foliage leaf; *inf.*, inflorescence; *l.s.*, scar of foliage leaf; *l.*, lenticel; *n.s.*, new stem which is the elongated axis of the bud (*t.b.*); *s.l.*, scale-leaf; $s^1.l^1$. scale-leaves that clearly represent foliage-leaf bases; *s.s.*, scars of scale-leaves; *t.b.*, terminal bud; *v.s.*, scar of vein; *p.*, leaf stalk.

the scale-leaves, one by one, have dropped off. They were so numerous, so strong, and, in some cases, so spreading at the base, that when they fall they leave *ring scars*, or *girdle scars*, at the base of the bud axis that supported them (Fig. 146).

Further development brings the leaves and flowers to their perfection towards the end of May. The last Sunday of this month is " Chestnut Sunday." Throughout the summer the leaves, stems, and flowers carry out their various functions, and by September the " conkers," the seeds in the fruits of the Horse Chestnut, are formed. Although there were so many flowers on the long axis of the inflorescence, only two or three fruits are formed on each spike, because many of the flowers are male only, that is, they have stamens but no carpels.

Obviously the development of flowers at the tip of the bud makes any further growth in length at this point quite impossible. If the matter were left here it would mean that our Horse Chestnut trees, once they were old enough to produce flowers, would have many very curiously stunted branches. Compensation is, however, found in a most interesting way.

Terminal buds of the Horse Chestnut that contain a rudimentary inflorescence have, except in rare cases, only two pairs of foliage leaves. When such a bud bursts and its axis elongates, axillary buds develop very quickly in the axils of the upper pair of foliage leaves. These are naked buds. As they are not going to persist through the winter, they do not need protecting scale-leaves. It would, in fact, be bad economy for them to be so hampered, because it is their business to grow into leafy stems in the shortest possible time. As no fall of scale-leaves precedes their expansion, naturally there are no girdle scars at the bases of these stems which may grow to a length of 2 or 3 inches, bearing two or three pairs of small foliage leaves and ending in a terminal bud (Fig. 145). The growth of these short, lateral branches is seen most plainly in autumn when the foliage leaves have fallen. If both buds have developed, the stems project, one on either side of the saddle scar left by the inflorescence. Excellent catapults are made of such " forked " stems.

In the Horse Chestnut it is not usual for the axillary buds to contain flowers. Nor, of course, are they found in all terminal buds. In such flowerless buds the number of foliage leaves is greater and the growing point retains its individuality. It is free to go on growing. If it, in its turn, terminates in a flowerless bud another length of stem is added the following year, still in the same straight line—and so on. The production of such a definite *one* limb is known as *monopodial* development.

When monopodial growth is interrupted by any cause, as by flower production in the Horse Chestnut, the axis that continues the onward growth is a side branch of the main axis, and at first there is an angular interruption in the straightness of the branch. Later growth probably smooths out the angularity, so that a whole long branch, which may be made up of a branch of a branch, appears monopodial, whereas it is by no means a continuous axis. Such a branch is termed a *sympodium*.

The growth then, in the Horse Chestnut, is both monopodial and sympodial. The great majority of the buds in this tree are permanently dormant.

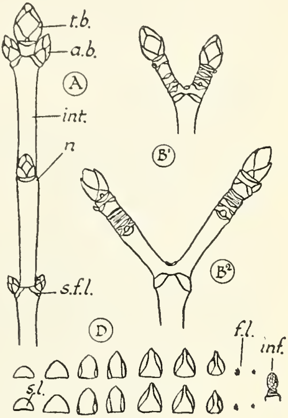


FIG. 147.—Sycamore. A, Twig. B^1, B^2, Twig showing forking after the formation of an inflorescence (see Fig. 145). D, Dissection of a bud. *a.b.*, axillary bud; *f.l.*, foliage leaf; *inf.*, inflorescence; *int.*, internode; *n.*, node; *s.f.l.*, scar of foliage leaf; *s.l.*, scale-leaf; *t.b.*, terminal bud.

The branching of the Sycamore closely resembles that of the Horse Chestnut (Fig. 147). In the Ash the black terminal bud always continues the onward growth of the axis, which is, therefore, a monopodium (Fig. 177).

The difference between the Brussels Sprout bud and that of the Horse Chestnut is only one of degree. Like some of the Horse Chestnut buds the Brussels Sprout is naked. As a matter of fact the bud scales of the Horse Chestnut are themselves the bases of undeveloped foliage leaves. That this is so is seen by the fact that the inner scale-leaves often divide into tiny leaf-blades at their tips (Fig. 146 (3)).

At first sight a more fundamental difference seems to be the presence of axillary buds in the Brussels Sprout. This, however, is but an illusory distinction. When a longitudinal section of a Horse Chestnut bud is examined with the microscope, buds are distinguished in the axils of the foliage leaves. They are at this stage extremely rudimentary, but they are definitely present.

The Age of a Twig.

When the axis of a bud expands to form a new length of stem, the fallen bud-scales leave ring scars, or girdle scars, at its base (Fig. 146). Thus the girdle scars mark the beginning of a new year's length of branch and the interval between two sets of scars indicates the amount of growth in any one year. In the older parts of a tree the scars have been shed with the bark, but as long as they persist on a branch its age can be determined by counting the sets of girdle scars.

The Beech Bud.

Girdle scars are very plainly marked on Beech twigs (Fig. 165), because here, also, the bud is protected by a large number of paired scale-leaves, some of which are completely circular at the base.

The simple leaves of the Beech grow alternately on the slender twig; therefore the axillary buds and the branches to which they give rise are also alternate. The branching is, moreover, generally sympodial, as in so many of our trees, in the Lime, for instance, and Elm and Hazel (Fig. 188).

The reason for this sympodial growth is found in the behaviour of the terminal bud. Very frequently this does not develop properly, but shrivels in the early spring almost as soon as it is formed. It is then the work of the axillary bud immediately below the useless terminal bud to function as a terminal bud and continue the elongation of the stem. In such a case each new length of stem is always a lateral branch of the axis that precedes it. The slight angularities disappear and the branch appears monopodial.

Both Beech and Lime buds are easily dissected, for their scales are free from resin. There is, however, special protection inside these buds, for most of the foliage leaves have two enveloping attendant scales, called *stipules* (Fig. 148). In the Beech the two or three leaves that surround the tip of the axis are generally not so protected. When the bud expands and the scale-leaves drop off, the stipules still persist, although their work is over. For two or three weeks they remain somewhat loosely attached at the base of the leaf-stalk. Then they, too, fall.

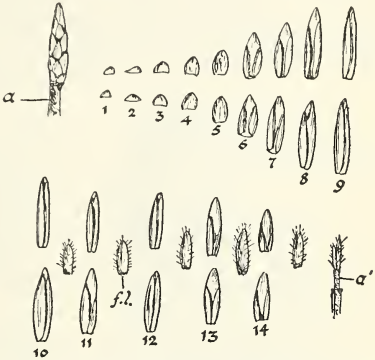


FIG. 148.—Dissection of a Beech bud. 1–9, Pairs of scale-leaves which are stipules without foliage leaves. 10–14, Pairs of stipules. *a.*, axis that bears the bud ; *a*¹., axis within the bud ; *f.l.*, foliage leaf.

In Beech and Lime it is clear that the protecting scale-leaves of the buds are stipules which have no related foliage leaves. In the Horse Chestnut and Sycamore the bud-scales represent the bases of foliage leaves. Frequently in the Horse Chestnut the innermost scales are fluffy at the tip, and slightly divided (Fig. 146 (3)). This morphological character of bud-scales is very clear in the buds of the Flowering Currant, but the gradual transition from bud-scale to foliage leaf is seen at its best in the Bird Cherry (Fig. 149). The small red bumps on the leaf-stalks of Cherry trees are extra-floral nectaries. Probably they prevent marauding insects from visiting the flowers. Ants, which would be of little use in bringing about pollination, are satisfied with the honey provided on the vegetative parts and do not enter the flowers.

A study of various leaf-buds is a wonderful lesson in packing. In Beech and Sycamore the individual leaves are folded backwards and forwards, just as we all made paper fans when we were very young. In the Lime the leaf is folded along the midrib like the cover of a book. In the Plum the blade curls round like a paper spill. In the Apple and Pear the edges curl in towards the midrib of the leaf.

The Wood and Bast.

The stem bears its leaves in such a way that they are well placed in relation to light and air. Furthermore, it is the indirect means of supplying them with mineral solutions. It is also along the stem that manufactured foods, as distinct from raw materials, travel. There are two separate transport systems in the stem. The raw materials travel in the vessels of the wood, or *xylem*; the manufactured food is carried by the bast, or *phloem*. There is no possibility of collision, for the systems are distinct one from another.

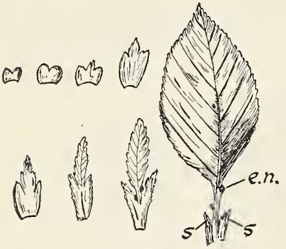


FIG. 149.—Bird Cherry, showing the transition from scale-leaves to foliage leaf. *e.n.*, extra-floral nectary; *s.*, stipule.

The course followed by the raw materials may be seen by allowing the base of a Brussels Sprout to stand in red ink for a day. When the stained base is sliced away the new basal surface is white with, perhaps, a ring of red dots or, more probably, a complete red circle. A longitudinal section of the bud shows that the apparent dots are the cut ends of long red strands, one appearing on either side of the section (Fig. 144). There is just the same appearance in the longitudinal section if the strands are united into a complete ring.

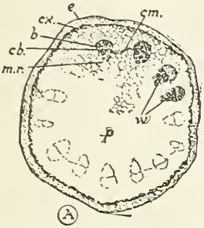
Internal Structure.

Microscopic examination shows the strands to be made up of numbers of hollow cylinders, placed end to end, whose walls are of wood. It is along these wood vessels that solutions travel to the leaves and along these only. No other part of the axis is stained red. On piecing together the evidence gained from the two sections, it is clear that the strands of wood are disposed in the axis either in an interrupted or in a connected circle of vascular bundles.

This experiment should now be repeated with an elongated stem. The stem of a Delphinium, or Sunflower, or Geranium gives the same result.

If the cut end of such a stem or, better still, a prepared microscope section be examined with a hand lens, the more intimate structure can be seen.

A transverse section of the stem of the Sunflower, stained and mounted on a slide, shows three regions in the stem. There is : (1) The ring of *vascular bundles ;* (2) The *pith* that these enclose ; and (3) The *cortex* that surrounds them which is bounded by the *epidermis* (Fig. 150).



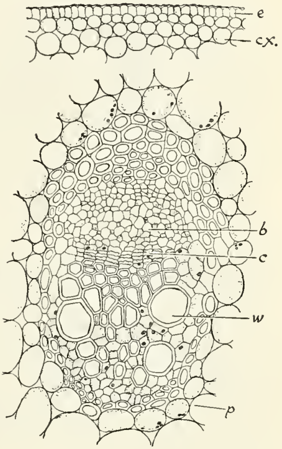


FIG. 150.—A, Transverse section of a young dicotyledonous stem (Aristolochia), as seen with a hand lens, showing the ring of vascular bundles. *b.*, bast; *cb.* or *c.*, cambium in the bundle; *cm.*, cambium forming between the bundle; *cx.*, cortex; *e.*, epidermis ; *mr.*, medullary ray; *p.*, pith; *w.*, wood. B, A drawing of one vascular bundle of Creeping Buttercup as seen under the microscope.

The cut ends of the wood vessels of the bundles are oval or round spaces which vary very much in size, but which agree in having thick and deeply stained walls. Beyond each group of vessels there is a roundish mass of cells quite different in shape and arrangement. These make up the bast, or phloem, which conducts the manufactured food.

Between the wood and the bast there is a layer of extremely delicate cells, the *cambium.* These cannot be seen with the hand lens, but it is entirely due to their very active division that the stem increases in thickness. The rays of tissue that separate the bundles, extending from the pith to the cortex, are the *medullary rays*.

Secondary Growth.

Examination of a section of a Lime twig shows a more compact arrangement of the cells, because the activity of the cambium has given rise to a very great increase of tissue in the stem, particularly in the wood (Fig. 151).

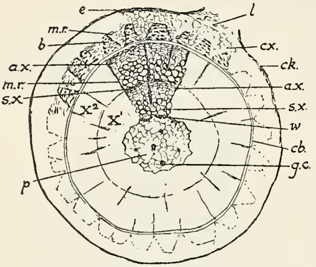


FIG. 151.—Section of Lime twig, two years old, as seen under a hand lens. *b.*, bast formed from cambium; *cb.*, position of cambium; *ck.*, cork; *cx.*, cortex; *e.*, dead epidermis; *g.c.*, gum cell; *l.*, lenticel; *m.r.*, medullary ray; *p.*, pith; *w.*, wood of original vascular bundle; X^1., ring of wood formed by cambium the first year; X^2., ring of wood formed by cambium the second year; *a.x.*, autumn wood; *s.x.*, spring wood.

Annual Rings.

There is no longer an interrupted circle of vascular bundles. The wood vessels are arranged round the pith in unbroken rings: one, two, or three rings according to the age of the twig. The largest vessels of each year's growth are towards the centre. These were made by the cambium in springtime when sap was rising vigorously. Later in the year smaller vessels answer the purpose. In autumn the vessel cavities are very small. In winter the activity of the cambium stops dead. It rests until the following spring, when it again takes up its work. The early-formed spring vessels have wide cavities, and it is the abrupt change, as seen in section, from the small cavities of the autumn wood to the large cavities of the spring wood that marks off the stem into the well-known *annual rings*.

The new bast that the cambium forms each year lies towards the outside of the stem. Beyond it is the cortex. Between cortex and epidermis there are now two or three layers of cork. Slender medullary rays glance through the section like darts of varying length. They, too, have been formed by the cambium.

All the tissues of the stem are continuous with similar tissues of the root. A different arrangement of the wood and bast gives a young root a characteristic appearance, but sections of old stems and roots are practically identical.

Cork.

The cork layer is impermeable to all solutions, and so all tissue outside the cork dies. *Lenticels* are patches of more loosely packed cork cells; they allow the oxygen necessary for respiration to pass in and the carbon dioxide to pass out. The green alga, Pleurococcus, that grows so commonly on tree trunks, occurs most densely around lenticels; apparently it benefits by the excess of carbon dioxide that is escaping at these points.

Bark.

Each year a new cork layer is formed some little distance within the old. Thus the layer of tissue outside the cork, dead because it is cut off from the plant's food and water supply, becomes each year a little thicker. This dead layer is the *bark* of the tree.

Similar cork formation heals wounds caused by broken-off branches or cut initials. Owing to the formation of successive layers of cork the initials on a Beech trunk, for instance, appear more and more sunken as the years pass.

Knots in Wood.

Certain details of internal stem structure are seen in the knots of wood in floor planks. A plank is a longitudinal section of a tree trunk. The knot is a section of a branch growing out from it.

In the Botanical Section of the Natural History Museum, South Kensington, at the top of the stairs to the left, are some excellent sections of tree trunks. They are so highly polished that many details of structure can be seen. Moreover, the rings of growth are not only dated, but the dates are related to certain events of historical interest: a most impressive way of giving the realisation of age. Many provincial museums have similar exhibits.

The bast, as seen in section, forms a continuous layer on the outside of the stem, just underneath the bark.

The Passage of Manufactured Food.

If a ring 2 inches wide is cut round the main stem of a young woody plant so that all tissues outside the wood are removed, the transport service of the bast is at an end. The food made by the leaves travels as far as the cut, but can go no farther. The downward pressure of the food solutions makes a circular bulge at this level. This means that the root is deprived of food just as effectually as in the root-pressure experiment, where the whole leafy crown of the Fuchsia had been removed. As a result of food shortage the root dies, and the rest of the plant shares its fate.

By such a destructive experiment it may be proved that manufactured foods really do travel along the bast. In the country a young tree growing in a tangled thicket may be experimented upon, or a small potted plant of Lilac, or Manitoba Maple, or Poplar may be used for this experiment. A Fuchsia is not much use in this case. It drops its leaves so readily that the experiment, for this reason, is not sufficiently conclusive.

Stems of Monocotyledons.

If the stem of Indian Corn, or of a Tulip, Hyacinth, or Daffodil flower be put into red ink and left for a day or two, the coloration in the cut stem is seen to be different from that of the Brussels Sprout. The red dots, indicating vascular bundles, are scattered without plan against the background of stem-tissue.

A prepared slide of Indian Corn, examined with a hand lens, shows that each bundle has two large wood vessels, a little like motor goggles; two or three small vessels in a row point to the centre of the stem; beyond the two large vessels lies a mass of bast (Fig. 152).

In these bundles there is no cambium. Therefore even in perennial plants of this class, except in some few anomalous stems, there is no annual secondary growth in thickness. Each year, up to a certain period, the growing point of the stem develops an increasing number of bundles, so that each year the stem is thicker towards the apex. As the lower part of the stem is still slender this is a top-heavy arrangement. To ensure stability adventitious roots grow in numbers from the lower part of stem or trunk. It is these *prop-roots* that, like the guy ropes of a tent, keep the axis erect. Such roots may be seen growing on Palm trunks in any tropical house or in the public gardens of the South of England.

It is because of the absence of secondary growth that plants of this class (Monocotyledons) are useless for timber. The most that can be done with them is seen in the not entirely satisfactory hat-racks and tea-tables of Bamboo.

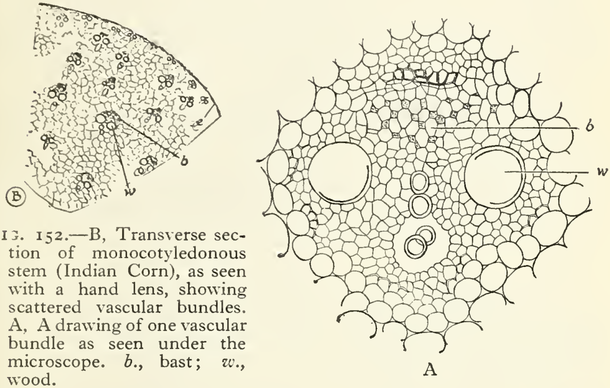


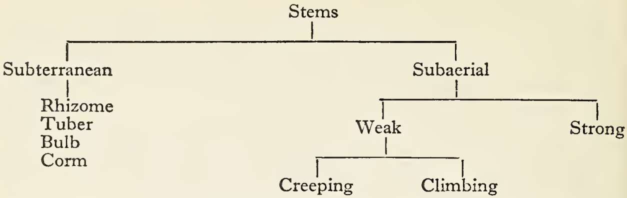
FIG. 152.—B, Transverse section of monocotyledonous stem (Indian Corn), as seen with a hand lens, showing scattered vascular bundles. A, A drawing of one vascular bundle as seen under the microscope. *b.*, bast; *w.*, wood.

Among stems there is great variety, both in external form and in habit of growth.

Classification of Stems.

Some are always underground and are called roots by the uninitiated. Of those that are above ground, or *aerial*, some have no power of maintaining an independent, upright position. They have, therefore, no alternative but to creep or climb.

The description of the different forms of stems will be taken in the order of the following table of classification :



Underground Stems.

The different underground stems are all adapted for storing food. The surplus food that is made in the green foliage leaves travels down to the rhizome, tuber, corm, or bulb, as the case may be. In this organ it is held in reserve in some carbohydrate form, such as starch, sugar, inulin, or as protein.

The underground stem is dormant for a considerable period of the year. It bears buds from which, at the proper season, stems, leaves, and flowers grow upwards. These owe their rapid growth to the available food store which has been held in readiness for them in the underground stem, and which is changed into some soluble form, so that it may travel.

The new foliage leaves then make food, which is stored as in the preceding year. Thus a *perennating organ* is re-formed to carry on the growth in each succeeding year.

Shoots that develop from some of the axillary buds break away from the parent and live independently. When new plants are formed in this way, without the intervention of seed, the process is known as *vegetative propagation.*

Rhizomes.

A typical *rhizome* is that of the Iris (Fig. 153). It is a stout stem that grows horizontally in the ground. Its stem-like character is seen in the fact that near the growing point it bears erect, sword-like foliage leaves. They are attached to the stem by such a spreading base that they bestride it, as a rider bestrides a horse. It is for this reason that they are said to be *equitant.* The whole length of the rhizome behind the tip is marked with rings which are the scars of withered leaves. The dots along their course are the scars of the veins of the leaves.

As they are stems, rhizomes cannot absorb solutions from the soil. Adventitious roots grow from their under surfaces to carry out this work and to help in anchorage.

The tip of the rhizome forsakes the horizontal direction of growth to turn upwards and carry the foliage leaves and flowers above the soil. Thus the direct onward growth of one year's length of stem comes abruptly to an end. The continuation of horizontal growth is made possible by the development of an axillary bud, a little way behind the growing point before this makes its upward curve. This axillary bud gives rise to a new length of stem that is a branch of the old one, and the Iris rhizome, like the Beech branch, grows sympodially.

Other axillary buds grow out into lateral branches. As the rhizome grows forward the hinder part rots away. This causes the lateral branches to become independent individuals. Vegetative propagation has taken place, and there are now two or three plants in place of the original parent.

There is no doubt as to the onward growth of the rhizome, for each year the Iris flowers in the garden are in a slightly different position. Each flowering stem is a little nearer the house, or a little farther from it, than it was the year before. The rhizomes may even creep under the hedge into a neighbour's garden if the tip is turned in that direction.

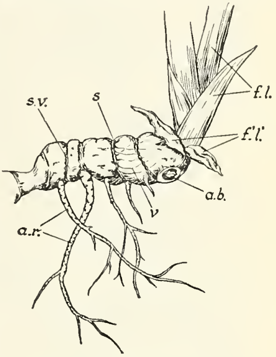


Fig. 153.—Iris Rhizome. *a.b.*, axillary bud; *a.r.*, contractile adventitious roots; *f.l.*, foliage leaves; *f*¹.*l*¹., dead foliage leaves; *s.*, scar of foliage leaf; *s.v.*, scar of vein; *v.*, vein of dead leaf.

Almost all that has been written about the rhizome of the Iris applies to that of Solomon's Seal. There is, however, this difference. The round scar, or "seal," on this rhizome is left by the decay of a whole shoot bearing foliage leaves and flowers (Fig. 154).

In each rhizome the constrictions of the stem delimit the growth of one year from that of the next.

Other sympodial rhizomes are the Couchgrass, Lily of the Valley, Mint, and White Deadnettle. The rhizome of Wood-sorrel is monopodial.

Vertical Rhizomes.

In many plants that have a sturdy tap-root, the leaves appear to grow from the root. The delicate leaves of the Carrot and the large leaves of the Turnip grow from the top of Carrot and Turnip alike. But this " top " is stem, not root. It is a short, thick, vertical rhizome (Fig. 143, A).

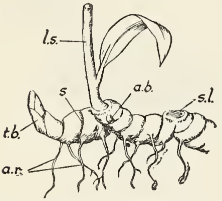


FIG. 154. — Rhizome of Solomon's Seal, showing parts of three years' growth. *a.b.*, axillary bud; *a.r.*, adventitious roots; *l.s.*, part of leafy shoot; *s.*, scar of scale-leaf; *s.l.*, scar of leafy shoot (" seal "); *t.b.*, terminal bud.

Root Contraction.

The rosette of Dandelion leaves grows from a similar, but slender, vertical rhizome (Fig. 182). As there is a slight elongation of this stem, year after year, it would seem natural for the rosette of leaves to rise, by degrees, above the ground-level. This is prevented by the contraction of the lateral roots. The cortical cells of these branch roots shorten, so that the roots themselves become shorter and thicker and draw the whole root system more deeply into the soil; in this way the rosette of leaves still rests upon the surface.

The adventitious roots of rhizomes also contract and counteract the tendency of the whole stem to follow the upward direction of the growing point.

Tubers.

The underground stem of the Potato or Artichoke begins as a rhizome and ends as a *tuber*. This is a change that puts an end to any further onward growth, either monopodially or sympodially.

The " eyes " scooped out in peeling a potato are axillary buds. When a potato " sprouts," these buds are shooting. A bud of the tuber sends a leafy stem upwards, and from the base of this stem adventitious roots grow down into the soil.

Many new potato plants are propagated vegetatively, in this way, from one tuber.

The Potato plant bears foliage leaves of two kinds. Those near the ground-level are small and simple. The others are pinnately compound with a varying number of leaflets. The buds in the axils of the compound leaves produce ordinary aerial shoots. From those in the axils of the simple leaves shoots develop that grow downwards into the soil as slender rhizomes, bearing scale-leaves of a triangular shape. Food manufactured by the compound leaves is stored in the underground shoots. These swell greatly to accommodate the reserve supply, and, in swelling, become tubers (Fig. 155).

On the Potato the spreading bases of withered triangular scale-leaves have left semilunar scars. These border depressions in which the axillary buds lie. The scars all have the same arrangement with regard to the apex of the tuber. At one end a small roughish scar marks the spot at which the swollen tuber broke away from the rhizome.

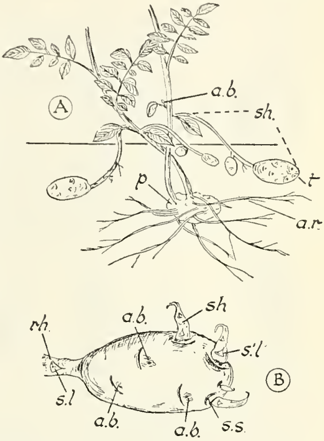


Fig. 155.—A, Potato plant (adapted from Strasburger). *a.b.*, axillary bud; *a.r.*, adventitious root; *p.*, Potato originally planted; *rh.*, portion of rhizome still attached to tuber; *sh.*, shoot developed from an axillary bud; *s.l.*, scale-leaf on rhizome; s^1*.l.*, scale-leaf on axillary shoot of tuber; *s.s.*, scale-leaf scar; *t.*, tuber. B, represents " t " later, when it, in its turn, is sprouting.

The structure of a bulb is more complex than that of a rhizome or tuber.

Bulbs. The Snowdrop bulb is so regular in its growth that, in spite of its small size, its study gives a very clear understanding of bulb structure.

The scaly wrappings on the outside of the bulb in the autumn should be carefully removed and arranged in a horizontal row. They are really four in number, but the first may come off in pieces or it may be absent because of the rub on the bulb in its various packings and journeys. If it is intact it is completely circular. The second wrapping resembles it. The third is semicircular. The fourth is merely a narrow strip.

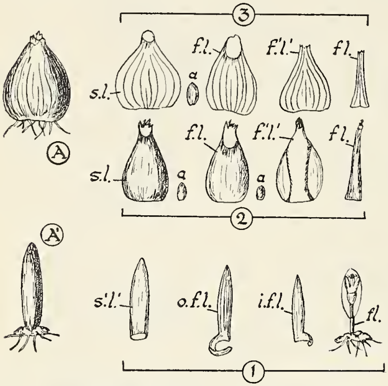


Fig. 156.—Dissection of Snowdrop bulb in autumn. A, The bulb. A^1, The central bud. 3, Remains, now scale-like, of parts that grew in the spring of *last* year. 2, White, fleshy remains of parts that grew in the spring of *this* year. 1, Dissection of central bud, showing young parts, ready to grow in the spring of *next* year. *a.*, axillary bud ; *f.l.*, circular base of outer foliage leaf; $f^1.l^1.$, semicircular base of inner foliage leaf ; *fl.*, base of flower stalk ; *o.f.l.*, outer foliage leaf with circular base ; *i.f.l.*, inner foliage leaf with semicircular base ; *s.l.*, base of scale-leaf of central bud ; $s^1.l^1.$, scale-leaf of central bud.

The thick white wrappings that follow are identical in number and in shape with the scaly ones. They should be so arranged in a row that each fleshy cover is exactly under the scale to which it corresponds. Those that are circular can only be satisfactorily removed by making a vertical cut downwards, followed by a circular cut around the base. In this second set of structures the narrow strip is tucked inside the incurving edges of the third wrapping.

The removal of the structures shows that they grow on a very short stem, therefore they are leaves. At least they are bases of leaves, because a shrivelled, irregular tip indicates that something has died away at this point.

A dissection of the bud, that now stands alone on the short stem, gives the clue to the morphology of the bulb (Fig. 156).

This bud is wrapped up in one bud-scale which is completely circular. Two foliage leaves follow, and a good dissection shows that the first of these has a completely circular base, while the base of the second is semicircular. The Snowdrop flower, enclosed in its bract, is in the centre of the bud.

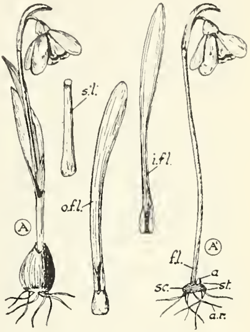


Fig. 157.—A, Snowdrop bulb the following spring, showing the development of the central bud (A^1) of the previous figure. The other drawings show the new shoot dissected. *a.*, axillary bud, which in autumn will have reached a stage like that of A^1 of the previous figure; *a.r.*, adventitious roots; *fl.*, base of flower stalk; *o.f.l.*, outer foliage leaf with circular base; *i.f.l.*, inner foliage leaf with semicircular base; *$s^1.l^1$.*, circular scale-leaf of bud; *sc.*, leaf-scars; *st.*, abbreviated stem.

If these four parts of the bud are arranged to form a third horizontal row, their relationship to the members of the first and second row is clear. Evidently the first thick circular wrapping is the scale-leaf that protected the bud of a year ago. The next two are the bases of the green foliage leaves. The narrow strip is all that remains of last season's flower stalk.

The scales are similar structures, but a year older still. A year ago they, too, contained a reserve store of food, which they gave up to the leaves and flowers that grew in the spring. If the bulb that is being examined had not been destroyed, the present white fleshy leaf-bases would have been similarly depleted, so that they in their turn would have become thin and brown and scaly.

Growth of the Bulb.

In the spring, when the bulb is in the soil, adventitious roots grow from the base of the short stem. The water they absorb causes the expansion and growth of the bud-structures, and the whole bud pushes upwards. The bud-scale splits. The leaves elongate and turn green. The flower stalk lengthens and the flower expands (Fig. 157).

As long as they live the green foliage leaves are making food. In a soluble form this passes down to the spreading leaf-bases, where it is stored. As a result the bases of the leaves become larger and larger, and when, finally, the green blades above the ground die, the bases remain below the ground as white fleshy structures with a dead and shrivelled tip. Thus the bulb, year after year, is renewed from the centre.

Gardens are apt to look untidy when the flowering time of bulbs is past, because, if the bulbs are to be any good at all next year, the leaves must not be cut off until they have lost the power of manufacturing food. If bulbs grow on a lawn, for the same reason, the lawn cannot be mown until the work of the leaves is at an end.

Daughter-Bulbs.

In the dissection of the bulb axillary buds are found in the axils of both scaly and fleshy leaf-bases (Fig. 156). They grow as the central bud does, and in time form daughter-bulbs. Later, owing to the casting-off of old leaf-bases, they are set free as separate individuals. This is another case of vegetative propagation.

The mathematical regularity of the Snowdrop bulb depends upon the fact that, each year, two foliage leaves grow from the central bud. In the Daffodil there is no constant number, therefore the number of leaf-bases varies in different bulbs.

The Tulip Bulb.

The structure of the Tulip bulb is different. As its foliage leaves grow on an elongated stem, well above the ground, it is plain that they cannot contribute to the renewal of the bulb directly. They do so indirectly, however, by sending the food they make down through the stem to certain short, modified underground leaves, whose work it is, not only to store reserve supplies but, at the proper season, to pass it on to the central bud of the bulb. When this develops, its foliage leaves in their turn make food, which is stored in the modified underground leaves and so a new bulb forms, year after year.

To define a bulb as an underground stem is not altogether satisfactory because it is largely made up of leaf-structures. To call it an underground bud is even more open to criticism. A bud is essentially something new ; but most of the parts that make up the bulb are essentially old. They are either the bases of foliage leaves that grew in a time now past or, like the scales of the Horse Chestnut bud, leaf-bases that have never been more than bases.

This must be indicated in the definition. A bulb, then, is a perennating organ that is made up of a number of leaf-bases that grow on a much abbreviated stem and surround a central bud.

Although there are many points in which a bulb differs from a bud such as that of the Horse Chestnut, there are, at the same time, many fundamental points in which they agree.

Comparison of Bulb and Bud.

In both there is an extremely short axis, bearing overlapping leaves; in the bulb this axis is permanently stunted; in the bud it elongates to form a new branch.

The leaves grow extremely close together, so that each *internode*, that is, the space between the insertion of one leaf and the next, is very short; in the bud the internodes elongate with the elongation of the axis.

In bulb and bud alike axillary buds are produced in the angle between leaf and stem.

To sum up: The bud is an undeveloped branch which only exists by virtue of its attachment to the parent plant. The bulb is a modified branch that contains the bases of foliage leaves that grew in previous years, as well as the leaves and flower of the year that is to come. The bulb is an entirely independent individual, living its own independent life. It is a perennating organ that, by storing supplies of reserve food, makes the growth of new aerial parts possible in each succeeding year.

In a *corm*, as in the tuber and the rhizome, the surplus food made by the foliage leaves is stored up in the stem, which in this case is round and globular.

Corms.

Plants with corms include Gladiolus, Cyclamen, and Crocus. The latter should not be confused with the Prairie Crocus or Pasque-flower, which does not form corms.

On this stem, as is seen in the Crocus corm in autumn, there are a number of fibrous coverings. As these grow on a stem, and as they have buds in their axils, they are evidently leaves. In shape they are all circular. Irregular circular scars persist on the stem when they are removed. The axillary buds are just a little above the level of the scars; evidently the stem has elongated somewhat since their formation (Fig. 158, B).

Two or three larger buds grow at the top of the corm. Each is surrounded at the base by fibrous structures. These are small. They are smoother, too, and paler in colour than those already removed.

It is a good plan to cut away the corm on four sides, so that the largest bud rests on a square pedestal of stem (Fig. 158, α). The numerous bud-scales should be removed with care, so that no other part of the bud is broken in the process. When they are arranged in a row they are seen to approximate in number to the fibrous layers that covered the corm. Like these, too, they are all circular. The little stem, moreover, from which they have been removed, is round and globular—it is, in fact, a corm in miniature (Fig. 158, β).

It is now evident that, apart from the difference in age, the young bud-scales and the old circular fibrous wrappings are one and the same. A year ago the latter were white and living and enclosed the flowers and leaves.

When the foliage leaves of the bud are examined it is seen that they expand a little at the base. It is in their axils that the large buds develop. It is their spreading bases that persist a year later as the little brown frills surrounding the bases of the buds that grow at the top of the corm.

The Growth of the Corm.

The mode of growth is like that of the bulb. Adventitious roots grow from a stumpy round disk at the base of the corm and, by absorbing water, give the stimulus for the expansion of the buds. The wood vessels up which the water passes to reach the buds are seen as yellow strands in the white bulk of the corm (Fig. 158). The bud elongates and the scale-leaves unfold. The pale foliage leaves grow and become green in the light.

The parent corm *decreases* in size because of the depletion of its food store. The daughter corm *increases* in size because it is, in its turn, storing food made by the foliage leaves. Thus the new corm is formed above the old one, and it is only the contraction of the adventitious roots that keeps it from rising above the level of the soil.

The old corm diminishes to such a degree that in the

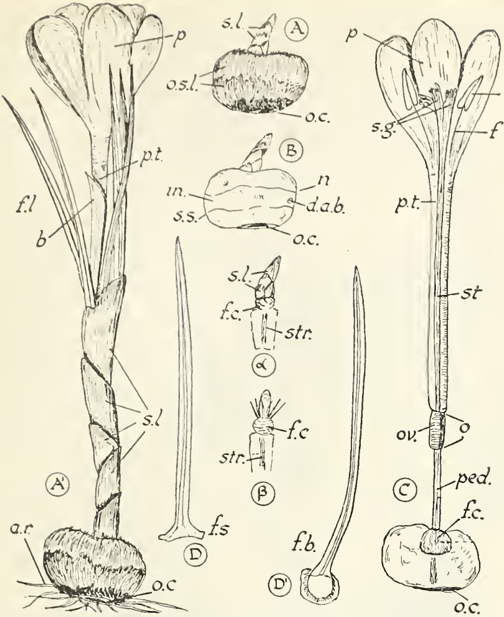


FIG. 158.—Crocus. A, Corm as planted in October. B, The same with wrappings (old scale-leaves) removed. α, Corm cut to show the whole bud. β, The same with the scale-leaves of the bud removed. A^1, The plant as seen in the following March; C, Longitudinal section of A^1, when scale-leaves and foliage leaves have been removed. D, D^1, Foliage leaves removed from C. *a.*, anther; *a.r.*, adventitious roots; *b.*, bract; *d.a.b.*, dormant axillary bud; *f.*, filament; *f.b.*, foliage leaf with circular base; *f.c.*, future corm; *f.l.*, foliage leaf; *f.s.*, foliage leaf with spreading base; *in.*, internode; *n.*, node; *o.*, inferior ovary; *o.c.*, remains of last season's corm; *o.s.l.*, scale-leaves of bud of previous year; *ov.*, ovule; *p.*, leaf of perianth; *p.t.*, perianth tube; *ped.*, flower stalk; *sg.*, stigma; *s.l.*, scale-leaves of bud; *s.s.*, scar of scale-leaf; *st.*, style; *str.*, vascular strands conducting water upwards.

following year it is nothing more than a stumpy disk from which spring the adventitious roots (Fig. 158, A^1).

Bulbils.

An unusual method of vegetative propagation occurs in the Lesser Celandine. Some of the axillary buds, instead of developing into ordinary branches, produce an adventitious root. Food manufactured by the foliage leaves is stored in this. The adventitious root then enlarges out of all proportion, so that finally the structure is almost all root, the bud part being scarcely recognisable (Fig. 159).

These curious *bulbils* separate from the parent and give rise to new and independent plants. In appearance they resemble exceedingly small new potatoes. Often they are washed from the parent plant in numbers by a heavy shower and lie in collections on the slope of a Celandine bank. In many country districts they are, for this reason, spoken of as " potato rain."

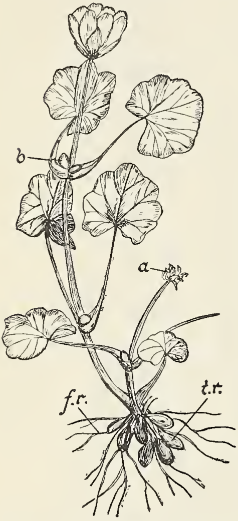


Fig. 159.—Lesser Celandine. *a.*, head of achenes; *b.*, axillary bulbil; *f.r.*, fibrous root; *t.r.*, tuberous root.

Creeping Stems.

The upright growth of stems is a tropic response to the stimulus of gravity. Stems are *negatively geotropic*. They are able to maintain the erect position partly because they are provided with internal mechanical, or strengthening, tissue, such as the vessels of the wood; partly, also, because the individual living cells are extremely turgid, that is, so full of cell-sap that the walls are extended to their utmost capacity. The result is that all the living tissues are taut.

In spite of possessing these apparent advantages, certain shoots forsake the upright position and creep along the ground. Contact with the soil induces the creeping stem to put out adventitious roots, which always grow downwards from the *nodes*, that is, from those parts of the stem where the leaves arise. As the buds in the leaf axils at the same time develop into upward-growing shoots, the result is that a number of young plants are formed, attached by slender stems to each other and to the parent plant. Rotting of the connecting stems brings about the separation of the daughter plants, which thus have a vegetative origin.

This formation of *runners* occurs in Creeping Jenny and Ground Ivy, in both of which the growth is monopodial.

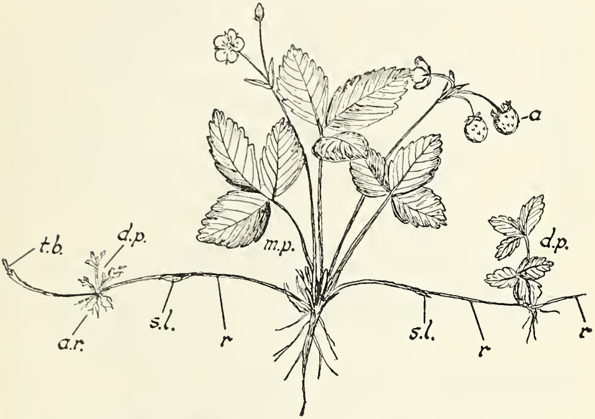


FIG. 160.—Runner of Strawberry. *a.*, fruit (achenes on a juicy receptacle); *a.r.*, adventitious roots; *d.p.*, daughter plant; *m.p.*, mother plant; *r.*, runner; *s.l.*, scale-leaf; *t.b.*, terminal bud.

When the runner is sympodial, as it is in the Strawberry and Cinquefoil, certain individual differences obtain (Fig. 160). The growing point turns upward to carry the leafy flowering shoot above the ground. Where the stem curves adventitious roots grow down into the soil. A bud in the axil of one of the leaves develops into a shoot that grows forward along the ground. This is a branch of the original runner. In due season its growing point turns upward; an axillary bud continues the onward growth, and so a long, sympodial runner, often branching freely, spreads over the surface of the soil. By the severing of the connecting stems, which bear small scale-leaves, a number of daughter plants break away from the original parent.

By means of their adventitious roots such plants get a ready supply of water and stake a claim by covering a considerable area of ground, thus interfering with the growth of would-be rivals. They are, however, often at a disadvantage with regard to light and air.

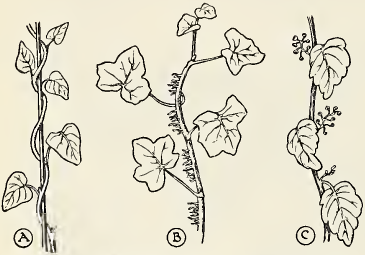


FIG. 161.—Methods of climbing. A, Convolvulus (Bindweed). Twining main stem. B, English Ivy, adventitious roots. C, Ampelopsis, adhering disks.

Climbing Plants.

Other weak-stemmed plants overcome this disadvantage by adopting the climbing habit, and making use of sturdy neighbours to help them to raise their stems and leaves well above the undergrowth. They are generally extraordinarily successful and really gain the light that is their object.

Various devices adopted by plants have led to their success as climbers.

Twining Main Stems.

In some cases the main stem twists round a support (Fig. 161, A). This support may be nothing more than a thin string fixed for a Runner Bean, or it may be a sturdy forest tree, round which the Honeysuckle twines.

The Honeysuckle is the only British plant with a twining stem that can encircle a tree. In Central Canada the common Honeysuckle, *Lonicera glaucescens*, twines round shrubs and small trees. There are many such climbers in South America; thick-stemmed lianes that twine around trunks and branches often exert so much pressure, that the limb of the tree becomes malformed as a result of the support it gives. The curious spiral walking-sticks sometimes seen are branches from which such a liane has been cut away.

A twining stem gets a hold on its support because of inequality in its growth. At first the stem is erect, as seen in the Convolvulus, the tiresome " bindweed " of the garden. Then the upper part waves out practically at a right angle from the vertical. Growth is more rapid on one side of the stem than on the other. The inequality of growth is an irritable movement, or *circumnutation*, induced by the force of gravity. The greater growth of the one side produces a curve in the stem, but only in its young growing region. When this region comes in contact with a support the inequality of growth on the two sides of the stem induces further curvature, with the result that the climber clasps the support and twines around it as long as growth persists.

The turn of the spiral made by a twining stem depends upon which side grows the more rapidly. Honeysuckle, Hop, and Black Bryony twine in a clockwise direction. The turn of the spiral in the Runner Bean and Convolvulus is counter clockwise.

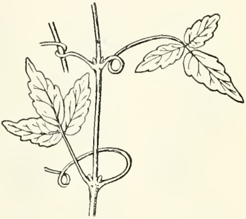


Fig. 162.—Clematis, climbing by means of twining leaf-stalks.

In other cases plants climb by means of modified lateral appendages. In some plants, as in Clematis and Garden Nasturtium, the appendage so modified is the leaf-stalk, or *petiole* (Fig. 162). In others, as in the Vine (Grape) and Sweet Pea, the climbing organs are *tendrils*. The grip of both petiole and tendril on the support is governed, as in the case of twining stems, by inequality of growth on the two sides.

Tendrils.

In the Sweet Pea the climbing habit has led to a sacrifice of some of the leaflets of the compound leaf. All but the lowest pair have been modified to form tendrils. For this reason the tendrils are in pairs and an odd one terminates the leaf.

As leaves are the great food-manufacturing centres of plants, this reduction in their number is a very real sacrifice.

By way of compensation there are wings, or flaps, on either side of the stem, and these carry on the work of carbon assimilation which is the normal function of foliage leaves.

In Vetches, where the number of leaflets is great and the number of tendrils few, there are no assimilating wings on the stem, because the leaflets are present in sufficient number to make all the food the plant requires.

At the base of the compound leaf of the Sweet Pea, near the axil, are two stipules which enclosed the leaf when it was very young. These stipules also compensate to some extent for the loss of assimilating area, as, unlike the stipules of Beech and Lime, they remain in permanent connection with the foliage leaf and are actively engaged in the manufacture of food (Fig. 163, A).

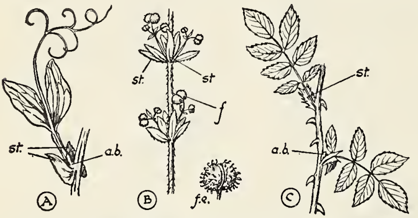


Fig. 163.—Methods of climbing. A, Sweet Pea (tendrils which are modified leaflets). B, Goosegrass or Cleavers (recurved hairs). C, Rose (recurved hooks). *a.b.*, axillary bud; *f.*, fruit (schizocarp); *f.e.*, fruit enlarged; *st.*, stipule.

The tendrils of the Vine (Grape) are morphologically distinct from those of the Sweet Pea. A Vine tendril always occurs opposite a foliage leaf, as do the clusters of Vine flowers and, of course, the bunches of grapes that follow the flowers. Judging, then, by analogy, the Vine tendril is a branch.

It has been suggested that the tendril is really a continuation of the main axis, and that it has been pushed to one side by a lateral branch which developed in the axil of a foliage leaf and then grew vertically onwards. If this be so, the growth is sympodial, as in Beech and Lime. It is, however, a difficult question, and other views as to the morphology of the tendril have been advanced.

In Ampelopsis, as in the Vine, the foliage leaves grow alternately on the stem. Opposite each leaf is a modified shoot, which is much more branched than the Vine tendril.

Adhesive Disks.

The little branches end in adhesive disks which cling to flat surfaces. Where these structures occur on the stem the opposite leaf has no axillary bud. Where there are no disks a bud, or a leafy branch that has grown from a bud, is present in the leaf-axil (Fig. 161, C). If the flattened disks meet no support, the individual branches curl, tendril-wise.

In the White Bryony the tendrils are unbranched. Furthermore, they do not merely curl where they are in contact with a support. The stimulus to curve is transmitted from the apex along the tendril. As the tendril is now fixed at two points, not only is a direct corkscrew spiral produced, but the part of the tendril attached to the parent plant turns in the opposite direction. Thus one half of the tendril coils to the right, the other to the left. Between these two parts is a neutral length (Fig. 164). The regular coiling draws the climber nearer to the support. The numerous coils and the reversed spiral allow for considerable play, so that in a wind the White Bryony may sway considerably, but the tendrils do not break.

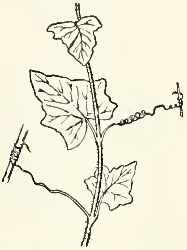


Fig. 164.—White Bryony, climbing by means of tendrils.

In Smilax two tendrils occur at the base of each foliage leaf (Fig. 168, B). In this case they are modified stipules.

Adventitious Roots.

The English Ivy climbs by means of adventitious roots which grow from the shaded side of the stem in stiff, brush-like groups (Fig. 161, B). The sole function of these roots is to cling, and for this purpose they secrete a sticky fluid. They absorb no food, therefore the Ivy is in no way parasitic. It does, however, kill the tree up which it climbs, because it effectually blocks the lenticels of trunk and branches. The more freely the Ivy grows, the greater is the area of the tree cut off from access to oxygen. Eventually the supporting tree loses in the unequal struggle and dies from strangulation.

The hooks of scrambling climbers of the bramble type are outgrowths of the epidermis. In the Garden Rose the hook is very readily separated from the stem. Its removal affects nothing more than the external skin, and a layer of cork quickly heals the slight damage caused. Hooks are found on the underside of the midribs of the compound leaves as well as on the stem (Fig. 163, C).

Recurved Hooks.

In such scramblers the growing tips of the shoots follow an intricate path, so that the stems weave in and out among the branches of the support. The hooks are slightly curved in most species of Rose and this gives the weak stem a definite advantage. The hold gained by the combination of the interweaving, together with the form of the epidermal hooks, adds greatly to the gardener's work in pruning ramblers.

It is by means of epidermal outgrowths that the Goose Grass, or Cleavers, climbs. These are very numerous and occur as recurved hairs covering the surface of stems and leaves alike (Fig. 163, B).

Recurved Hairs.

When Fuchsias, Geraniums, and similar plants grow in windows they are quite one-sided. The part of the plant that is towards the room appears all stems, and these are not erect, but inclined towards the window. The leaves all turn to the light. The sides of the stems towards the room, that is, the sides in the shade, grow more quickly than those that are in the full light, hence the inclination of the axes. Light has had a retarding influence upon the growth of the sides of the stems that face the window.

Retarding Influence of Light.

This retarding influence of light is well seen when two Broad Beans are allowed to germinate, one in a window, the other in a dark room or cupboard.

The latter grows much more rapidly than the former, but this is not the only difference between the two plants. The seedling grown in the dark is whitish, because the presence of chlorophyll depends upon light. Apart from this the plant in the dark shows other definite peculiarities. Its rapidly growing stem is very weak. The internodes are unusually long. The leaves are unusually small. Such plants are said to be *etiolated.*

Certain characters associated with the climbing habit in plants resemble those of etiolated plants.

Climbing plants have weak stems that grow rapidly, with the result that the nodes are far apart. At first sight the leaves do not appear to be particularly small. When, however, they are contrasted with those borne on erect stems their small size is apparent. Climbing Roses, Clematis, and Convolvulus never bear leaves comparable in size to the large radical leaves of the Foxglove, or to the stem-leaves (cauline leaves) of Delphinium, Horse Chestnut, or Ash.

In all climbing plants the root is relieved of a large part of its work. The climber depends for its support upon a sturdy neighbour. For this reason there is seldom any great development of the root system in climbers. Climbing Roses, such as the very freely growing American Pillar and Jersey Beauty, have roots that branch very sparsely in comparison with the spread of the aerial parts of the plant.

The Growing Region.

It is the growing region of a root that responds to the stimulus of moisture, of light, and of gravity (p. 258). Judging by analogy, the revolving movement of the tips of a twining stem suggests that here, too, the growing region may be just behind the apex. That this is so is proved by marking off equal intervals along a stem near its tip. This is not so simple a matter as in the root, because young leaves fold over the growing point. The lines, a centimetre apart, should be made with Indian ink behind the tip of a young Broad Bean or Sunflower stem, both of which grow rapidly. In the case of the bean, growth is found to take place along a distance of about five centimetres, the region of most active growth being about 1·5 centimetres behind the apex.

Response to Gravity.

Generally speaking, the response that main stems make to the stimulus of light and gravity is diametrically opposite to that of main roots. No matter in what position soaked beans are placed between gas-jar and blotting-paper, all the shoots grow upwards. When a young plant is inverted, as seen in Fig. 140, the stem makes a curve in the growing region and grows vertically upwards (p. 259).

The main stem, then, is *negatively geotropic*. Its different orders of branches, like the branches of roots, take various positions in relation to the earth's surface. Branches of the first order are often *diageotropic*, like creeping stems which grow parallel to the surface of the soil.

Response to Light.

Aerial stems are *positively heliotropic*. To show that this is so, one of the bean seedlings should be potted and transferred to a box that stands on end and is completely covered with black paper. A sheet of black paper, fastened with drawing-pins, replaces the lid. A hole, half an inch square, is cut in this covering paper, near the top. To do away with the necessity of watering, the plant-pot should stand in a saucer of water.

The box is then placed with the paper cover facing a window, so that rays of light enter through the square hole. The bean stem grows upwards, but not vertically so, for the growing region inclines more and more to the rays of light, and eventually the leafy tip of the stem appears in the aperture. A day or two later it has escaped from the darkened box and pushed its way through to the full light of day.

Elongation.

As regards the extent of their elongation, stems fall into one of two classes. A growing point may add to the length of the stem each year. Such a stem is said to be of *unlimited*, or *indefinite*, growth. In other stems the activity of the growing point stops abruptly at the end of a short period of growth, so that a *dwarf branch*, or *branch of limited growth*, is produced.

Dwarf branches serve different purposes. The special function of certain dwarf branches is to bear fruit.

Dwarf Branches.

All children in Britain have, at one time or another, hung paired Cherries over their ears. The short brown stem to which the two Cherry stalks are attached is a dwarf, or *fruiting*, branch of the Cherry tree.

A cluster of Black, White, or Red Currants grows from a smaller but similar dwarf branch. In topping and tailing Gooseberries the brown, shrivelled calyx is cut off from one end, but very often it is more than just the old flower stalk that is snipped off from the other ; the presence of a tiny bud or of a leaf shows it to be a much abbreviated branch.

In pruning Apple and Pear trees it is the long vegetative branches that are cut off in late autumn. The gnarled branches are left, because the "gnarls" are dwarf branches, which will bear the Apple or Pear blossom in the spring and the fruits in summer and autumn.

In these cases, once a dwarf branch always a dwarf branch holds good.

In the Beech this is not so. A branch that has borne Beech nuts for years may forsake what appears to be its fixed habit and grow indefinitely for several years in succession. After this it may again revert to fruit-bearing (Fig. 165).

The circular lines on all fruit branches are, of course, the scars of bud-scales that have been shed year after year. The growth in length of the stem each year has been so very slight that the girdle scars of one year almost touch those of the next, so that an almost continuous series is formed (Fig. 165, *d.b.*; *f.b.*).

In many cases dwarf branches are developed to serve an entirely different purpose, as, for instance, to make up for reduction in leaf-surface.

In no plant is this more clearly seen than in the Butcher's Broom. Its leaves are reduced to mere scales on the branches of unlimited growth. Some of the buds that occur in their axils grow out into

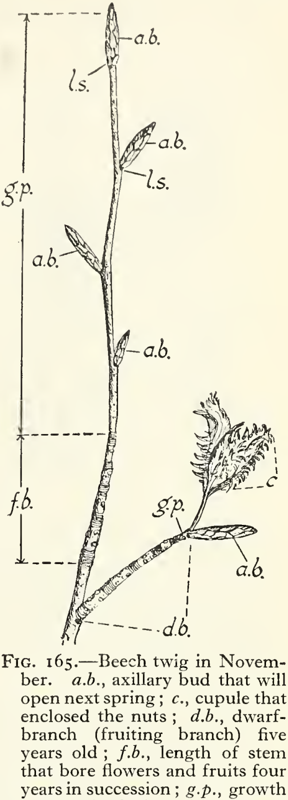


Fig. 165.—Beech twig in November. *a.b.*, axillary bud that will open next spring; *c.*, cupule that enclosed the nuts; *d.b.*, dwarf-branch (fruiting branch) five years old; *f.b.*, length of stem that bore flowers and fruits four years in succession; *g.p.*, growth in length during this present year; *l.s.*, leaf-scar.

other branches of unlimited growth. But the greater number of the axillary buds develop into dwarf branches that are leaf-like in shape (Fig. 166, A).

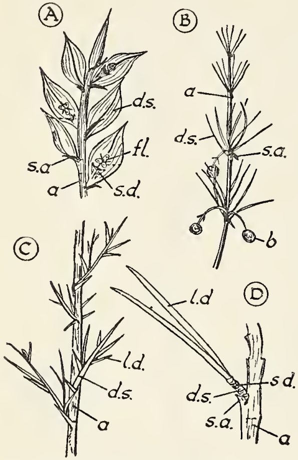


Fig. 166.—Dwarf shoots. A, Butcher's Broom. B, Asparagus. C, Gorse. D, Scotch Fir (Pine). *a.*, stem of unlimited growth; *b.*, fruit (berry); *d.s.*, dwarf shoot; *fl.*, flower on dwarf shoot; *l.d.*, foliage leaf on dwarf shoot; *s.a.*, scale-leaf on stem of unlimited growth; *s.d.*, scale-leaf on dwarf shoot.

Butcher's Broom is a *xerophyte*. It is a plant that grows naturally in dry situations, and the reduction of its leaves is a protective measure that prevents the plant from giving off too much water. because this giving off of water, or *transpiration*, takes place from foliage leaves.

The reduction of leaves, however, is attended with great disadvantages, because leaves also make the food for the plant. This difficulty is got over by the dwarf branches taking on the important work of carbon assimilation.

There is no doubt as to the branch nature of these structures. Not only have they developed from axillary buds, but each itself bears a scale-leaf on its central line. In the axil of this minute leaf a flower grows, followed later in the year by a bright red berry.

Such a dwarf branch as this, superficially resembling a leaf, is a *cladode*, or *phylloclade*.

The numerous needle-like outgrowths of the aerial shoots of the Asparagus are also phylloclades (Fig. 166, B). They arise, crowded together, in the axils of small scale-leaves, and are the assimilating organs of the plant.

The xerophytic adaptation in the Asparagus is inherited from the native wild Asparagus that grows in sandy soils. The young edible shoots of the cultivated Asparagus grow from a horizontal rhizome. Buds that develop in the axils of the scale-leaves give rise to more slender branches and these to more slender branches still. The ultimate branches are the clusters of crowded needle-like phylloclades.

In the Gorse it is only by close examination that dwarf branches can be distinguished from leaves (Fig. 166, C). The leaf is short, almost cylindrical, and ends in a sharp point. But the dwarf branch is also short, almost cylindrical, and ends in a sharp point. To distinguish them one from another their origin must be determined.

The leaf grows directly on the stem, and in the angle it makes with the stem there is either a bud or an axillary shoot.

The dwarf branch grows in the axil of a leaf and itself bears leaves.

The effect of this particular leaf-modification in the Gorse is to diminish transpiration. The loss of assimilating tissue is not so great in this case as in the Butcher's Broom. Still, there is a definite reduction in leaf-surface and, to compensate, not only do the dwarf branches take part in food manufacture, but four prominent ridges, found on the branches of unlimited growth, give an additional area of assimilating tissue.

In the Pine the "needles" grow on dwarf branches, two needles on each dwarf branch (Fig. 166, D). The only leaves borne by the branches of unlimited growth are small, rather woody, scales. In their axils the dwarf branches grow and bear both scale-leaves and foliage leaves. The foliage leaves

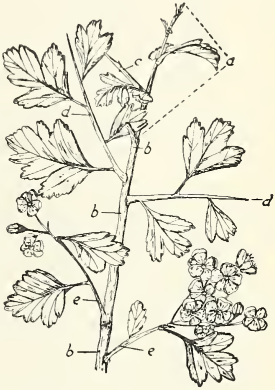


Fig. 167.—Hawthorn showing the various branch-forms (drawn in May). *a.*, stem of indefinite growth of the current year, bearing stipulate leaves; *b.b.b.*, stem of indefinite growth of the preceding year, bearing branches with foliage leaf-scars at their bases; *c.*, Dwarf branch which is a short thorn; *d.d.*, dwarf branches which are long thorns; *e.e.*, dwarf branches bearing flowers.

are the pine needles. There is no regular periodic leaf-fall in the Pine. When the work of the leaves is over they drop from the tree, still attached to the dwarf branch that bore them. In this case leaf-fall is more than just *leaf*-fall. It is *branch*-fall as well.

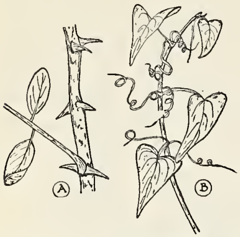


Fig. 168.—Modifications of stipules. A, False Acacia (thorns). B, Smilax (tendrils).

The branches of unlimited growth of the Hawthorn bear foliage leaves with leafy, persistent stipules (Fig. 167).

The axillary buds of these leaves may develop in four different ways: Some give rise to long branches, in every way resembling the axis that supports them.

Others develop into dwarf branches that bear the flower-clusters and, ultimately, haws.

From others, again, grow the protective short thorns. These are dwarf branches and frequently bear one or two leaves and axillary buds.

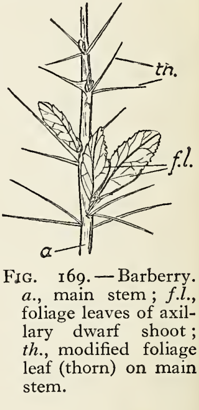


Fig. 169.—Barberry. *a.*, main stem; *f.l.*, foliage leaves of axillary dwarf shoot; *th.*, modified foliage leaf (thorn) on main stem.

Lastly some of the axillary buds produce the long thorns which bear flower-clusters in the axils of their leaves (Fig. 167).

Thorns.

It is not by any means the case that all thorns are dwarf branches. In the Gooseberry they are outgrowths from the pulvinus, that is, the spreading base of the leaf-stalk. In the False Acacia they are stipules (Fig. 168, A). In the Barberry they are modifications of the foliage leaves (Fig. 169).

Protection against Grazing Animals.

Thorns and prickles supposedly afford protection against grazing animals. It is a little disconcerting to find sheep and even lambs tearing and eating Blackberry branches, while donkeys and thistles are proverbially connected.

On the other hand, grazing animals certainly avoid Gorse, which is rich in suitable food. When it is put through the chaff-cutter it makes excellent fodder to mix with hay. This is a common practice in some districts of England, especially those in which the grazing land is rough.

Bitter Juices. The bitter juices found in most parts of Ranunculaceous plants also ward off animal attacks. A field is golden-yellow with Buttercups because horses, cows, and sheep, alike avoid them.

Hairs. Flocculent hairs, as well as preventing too great transpiration, protect the leaves on which they occur from being eaten. Coltsfoot and Mullein are never grazed. In the rolling process in the animal's mouth the hairs would come off, forming an unpleasant bolus, difficult to swallow.

Stinging Hairs. The stinging hairs of Nettles are a very specialised form of protection, possibly against the delicate noses of grazing animals. The hair is a hollow cylinder containing formic acid, which is also the stinging principle in the bite of an ant. The hair rests on a cushion of cells in the epidermal region and ends in an expanded bulb (Fig. 170).

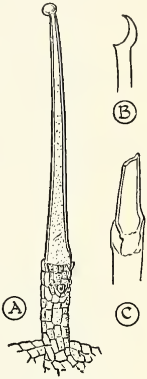


FIG. 170.—Stinging hair of Nettle. A, One hair. B, The tip of a hair that has been lightly touched enlarged. C, A bluntly broken hair.

The old rhyme says :

> "Tender-hearted stroke a nettle,
> It will sting you for your pains.
> Grasp it like a man of mettle
> And it soft as silk remains."

The scientific explanation of this truism is as follows. The bulbous end separates from the hair upon the slightest contact. The separation is effected in such a way that a scooping edge, rather like a doctor's hypodermic syringe, is left, and this pricks the skin. Through the puncture the formic acid enters. Mixing with the blood, it causes local blood-poisoning, which is attended with a certain amount of pain. When the Nettle is grasped roughly the hairs are broken lower down. The formic acid spills over the skin, but, as there is no puncture, it cannot penetrate.

It is interesting to note that plants that have no protection in themselves frequently grow among plants that have some weapon of defence.

Community Protection. It is difficult to pick the White Dead Nettle (which is not a Nettle at all) without getting stung, for almost invariably it grows among Stinging Nettles.

The beautiful fragile Stitchwort grows under hedges, as does the Hedge Parsley (Queen Anne's Lace). This habitat makes them very difficult of approach.

Cuckoo Pint (Lords and Ladies) grows most commonly under a Hawthorn hedge. If the Hawthorn terminates abruptly to be followed by Beech, no Cuckoo Pint is found growing under the Beech hedge.

PRACTICAL WORK

Examine twigs of various trees and shrubs of Western Canada (Manitoba Maple, Poplar, Birch, Saskatoon, Cherry, Viburnum) and study the different features of buds and branching described in the text.

The internal structure of stems is well illustrated by Sunflower, Willow, Manitoba Maple, Viburnum (Bush Cranberry), and Corn.

Additional features of stems may be illustrated by the following plants, most of which are generally available in Western Canada : Couch-grass, various other grasses with rhizomes, Solomon's Seal, Potato, Onion (bulb), Gladiolus, Strawberry, Honeysuckle, Convolvulus, Virginia Creeper, Runner Bean, Clematis, Sweet Pea, Vetch (Vicia), Vetchling (*Lathyrus ochroleucus*), Asparagus, Pine, Wild Gooseberry, Nettle, Coltsfoot.

CHAPTER XXIII

THE LEAF

In nursing homes and hospitals all plants and cut flowers are removed from the wards before nightfall, because of the interchange of gases that takes place between green plants and the atmosphere.

Always, every moment of the day and night, a plant is using up atmospheric oxygen and giving out carbon dioxide, for respiration never ceases until life itself comes to an end.

In daylight, in the case of green plants, another gaseous interchange is going on side by side with the respiratory process. This is the taking in of carbon dioxide and the subsequent return of oxygen, as a result of carbon assimilation.

In both processes gases pass in and out of the leaf by way of small apertures or mouths, called *stomata*. Actually to see these it is necessary to shave off the epidermis of a leaf, mount the thin layer on a slide, and examine it under the microscope. The mouths are then seen as gaps, each bounded by two sausage-shaped cells (Fig. 171).

Stomata.

To prove, without seeing them, that apertures are present in the epidermis is quite a simple matter. It is only necessary to boil some water in a beaker until all air-bubbles have escaped, then drop a leaf into the water. The air inside the leaf becomes hot and expands so much that it escapes in tiny bubbles, more particularly from the morphologically lower surface of the leaf, where the veins are most prominent. Not only, then, must gaps be present in the epidermis to make possible this escape, but they are evidently much more numerous on the under than on the upper surface.

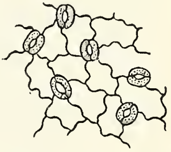


Fig. 171. — Epidermis from the under surface of a leaf, showing stomata.

To prove that air surrounding a leaf can pass into and through it, needs a little patience.

A large firm leaf, like that of the Laurel, should be fixed into a glass tube of relatively small bore, the connection between leaf stalk and tube being made air-tight with paraffin wax. The tube, which is drawn out to an open point at the other end, passes through one hole of a rubber stopper into a flask which contains a little water into which the point of the tube must dip. Passing through a second hole of the stopper is a short right-angled glass tube with a piece of rubber tubing fixed over its free end, so that it can be closed by a clip at will.

Some of the air that is in the flask above the water can be drawn out by suction through the right-angled tube. As soon as the lips are removed the rubber tubing must be fastened by the clip.

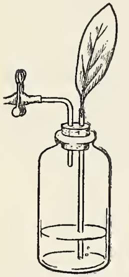


FIG. 172.—Experiment to show the passage of air through a leaf.

If the experiment is successful, that is, if all connections are air-tight, bubbles escape through the water from the pointed end of the tube that holds the leaf and continue to pass for some time (Fig. 172).

By suction air has been removed from the flask. Air from the leaf has taken its place. To make good the loss inside the leaf some of the air of the room has passed into it through the stomata of the epidermis.

Such, then, is the course of gases that enter the leaf, both in respiration and in carbon assimilation.

Gaseous Interchange.

The leaf area of a plant is so great in comparison with that of other members that it is natural to look upon leaves as being the chief organs concerned in the work of respiration. They certainly do respire freely, but so do all other parts of a plant; those that are not green as well as those that contain chlorophyll, those that are below the ground as well as those that project above it.

In spite of all this co-operative breathing, and in spite of the fact that, speaking generally, leaves only are concerned in carbon assimilation, the volume of oxygen given out in the daytime, as a result of carbon assimilation, is greater than the volume of carbon dioxide given out, at the same time, as a result of respiration.

In the daytime, therefore, when carbon assimilation is active, plants are adding to the oxygen content of the rooms in which they grow. When daylight fails and carbon assimilation ceases, respiration is still going on. Plants are then not only depriving the air of its necessary oxygen, but, more than this, they are adding to it an undesirable volume of carbon dioxide. It is for this reason that plants are removed from wards at night.

It is as a result of the intake of carbon dioxide that starch and sugar are made in green leaves.

Detection of Starch in Green Leaves.

The presence of starch in a leaf cannot be proved by dipping the leaf into iodine, because the strong green colour of chlorophyll masks the reaction. It is necessary, first, to get rid of the chlorophyll. As this is soluble in alcohol it can be removed by boiling the leaf in water, then leaving it in methylated spirit for some few days. The colour is extracted more quickly as a result of the preliminary boiling. A more rapid method is to boil first in water, then in methylated spirit over a small flame. If by chance the alcohol vapour ignites, it may be extinguished by putting a porcelain basin over the beaker. It is well to wash the colourless leaf in water to remove its brittleness. When it is put into iodine a brownish-blue coloration unmistakably proves the presence of starch.

It is, however, only in green leaves that starch is formed. If variegated leaves of Geranium or Japanese Maple are tested, starch is only found to be present in the areas that were green before decolorisation.

The Importance of Chlorophyll.

Starch is not made in the non-green parts of leaves, nor, evidently, does it travel to these areas from the green patches where it is made.

Certain peculiarities in the metabolism of ornamental "ribbon grass," make it an unsuitable subject for this investigation.

Although it is not seen, there is abundant chlorophyll in the red leaves of Copper Beech, Red Cabbage, and Japanese Cherry. It is merely hidden from view by the red pigment, and starch is made in the tissues of all these leaves.

One condition, then, that determines carbon assimilation is the presence of chlorophyll in the manufacturing area.

Even when leaves are green, the formation of starch in their tissues is still dependent upon two other factors ; one of these is light, the other is carbon dioxide.

The Necessity for Light.

A leaf of a Fuchsia plant, growing in a good light in the laboratory, will be found to contain much starch, especially towards the end of the day. If the plant is kept in the dark for two or three days no starch is found when the leaves are tested with iodine. The starch which was in the leaves when the plant was transferred to the dark has been turned into sugar. This has dissolved in the cell-sap and travelled away from the leaves.

As this removal of the carbohydrate from leaves goes on all through the night, and as no more is being made during the hours of darkness, a poor result is obtained on testing a leaf for starch early in the morning. Quite the best time to choose is the late afternoon of a sunny day, when the manufacture has been at its maximum.

Because of the great quantity of starch in the leaf this is not a good time to test for sugar. Nor is the early morning better, because of the escape of sugar from the leaf during the night. The best plan is to pick two or three leaves at the end of a very sunny afternoon when they contain much starch. They should be put into a corked gas-jar lined with damp blotting-paper, and kept in the dark for a few days. Sugar is then formed from the starch, but it cannot escape, and so its presence is readily detected when the leaves are tested with Fehling's solution (p. 161).

It might quite reasonably be argued that the failure to demonstrate the presence of starch, when leaves have grown in the dark, is not conclusive. Shoots are so sensitive to light that the whole plant may have suffered such a severe shock by being put into the dark that it has been unable to carry on its normal anabolic processes.

If access of light to two or three leaves only is prevented, this criticism loses its force.

Individual leaves of a Fuchsia plant growing in the laboratory, or, better still, of some deciduous tree or shrub in the immediate neighbourhood, should be covered with black or silver paper. It is essential that the paper should fit closely, and it does the leaves no harm to pin through them here and there.

Later, when both an exposed leaf of the plant and a covered leaf are tested, the former is seen to be loaded with starch, while the latter contains no starch, except just round each pin-prick where the light has penetrated.

Starch Printing.

This marked contrast may be seen in a single leaf if designs that coincide are cut out in the middle of the paper covering both leaf surfaces. On decolorising and testing with iodine, the cut pattern is seen sharply printed in dark blue against a light background. This is what is meant by "starch printing" in the tissues of green leaves (Fig. 173).

Starch, then, is found in green leaves that have grown in the light.

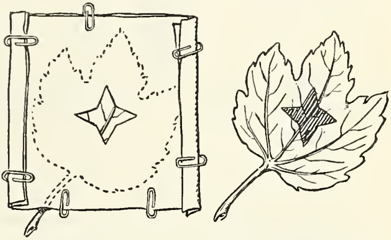


Fig. 173.—Experiment to show "starch printing" in leaves.

The Need for Carbon Dioxide.

To prove that carbon dioxide is essential for the manufacture of carbohydrates, the access of this gas to the plant must be prevented. The plant, therefore, must be grown in a limited space so that control of the gases reaching it is possible.

It is well to use two Fuchsia plants, so that one may serve as a control. Each is put under a stoppered bell-jar fitted with a U-tube which, in the control, contains bits of pumice over which the air passes freely. The Fuchsia under this bell-jar thus grows under normal conditions.

The other plant is in an atmosphere free from carbon dioxide, the gas having been removed by a very strong solution of caustic potash contained in a dish that is put under the bell-jar along with the plant (Fig. 174).

If the Fuchsia does not breathe it will die. For this reason it must be provided with a continuous supply of air. To ensure that this, also, is free from carbon dioxide the U-tube through which it enters is filled with soda-lime to trap the carbon dioxide. Only oxygen and nitrogen enter the bell-jar from outside.

In three or four days' time, when tests are made, no trace of starch is found in the leaves of this plant, while in the control it is found in abundance.

With regard to the physiological function of carbon assimilation, three points have now been definitely proved. The formation of starch only takes place in the presence of chlorophyll. It is dependent upon light. Carbon dioxide is necessary for the operation.

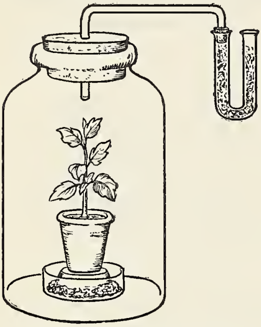


FIG. 174.—Experiment to demonstrate the need for carbon dioxide in starch formation.

The last condition is fairly obvious apart from proof. Carbon must be obtained somehow by the leaves if carbohydrates are to be made in their tissues, and the carbon dioxide of the air is a ready source of supply.

When oxygen is prepared from potassium chlorate, *heat*, supplied by the Bunsen flame, induces the chemical change.

In photography the changes that take place in silver salts depend upon the action of *light*.

In both cases it is on outside energy, in the one case heat, in the other light, that the chemical processes depend.

Similarly in the leaf the chemical processes that end in the building up of carbohydrates depend upon some readily available source of energy. As in photography, so in the manufacturing processes of leaves, this energy is supplied as light.

It is better then to discontinue the old term " carbon assimilation " in speaking of this important physiological process and to substitute *photosynthesis*. *Photos* is the Greek for light, and the use of the more modern term gives some indication of the nature of the process.

The synthetic formation of food in leaf tissues does not consist in *carbon* assimilation only. There is in addition assimilation of nitrogen and of sulphur, upon which the production of proteins depends.

The synthetic processes in the leaf are doubtless preceded by simple decompositions. There is no proof as to what actually takes place, but the succession of events is possibly the following.

The carbon dioxide taken in by the leaf probably breaks up into carbon monoxide and oxygen. The water sent up from the soil by the root may also undergo decomposition, losing oxygen. Possibly these oxygen atoms unite and are returned to the air.

$$\left.\begin{array}{l} CO_2 \rightarrow CO + O \\ H_2O \rightarrow H_2 + O \end{array}\right\rangle$$

There would then remain in the assimilating cells of the leaf carbon monoxide and hydrogen. The union of these would give formaldehyde :

$$CO + H_2 = \underset{\text{Formaldehyde.}}{CH_2O}$$

This is the simplest of the carbohydrates and, in solution, is the commercial substance known as formalin (p. 162).

Aldehydes have the power of polymerising. That is, by a readjustment of the molecules of their substance they form other, and higher, carbohydrates.

It is conceivable that every six molecules of formaldehyde might so polymerise as to produce grape-sugar :

$$6(CH_2O) \rightarrow C_6H_{12}O_6.$$

Undoubtedly sugar is the first product of assimilation in leaves. This may at once be carried away to various parts of the plant. On the other hand, it may lose a molecule of water and be retained, temporarily, in the leaf as starch :

$$C_6H_{12}O_6 - H_2O \rightarrow C_6H_{10}O_5.$$

For its subsequent removal it must again enter into composition with water to form sugar. It can then dissolve in the cell-sap and travel to other parts of the plant, and so disembarrass the leaf of a clogging supply of starch.

For permanent storage it is carried to roots, tubers, rhizomes, corms, or seeds, or to the cortex and medullary rays of stems.

In most cases a sugar solution is too bulky for permanent storage, although it is in this form that food is stored in the Carrot, and, more particularly, in the Sugar-cane and Beetroot.

Formation of Starch in the Dark.

More usually, when sugar reaches the storage organs it loses a molecule of water and starch is formed once more. In this second appearance of starch light plays no further part, for the storage organs are shut off from the sun, being either below the earth or within the pericarp of the fruit.

In such cases starch grains are formed from the sugar in the interior of special colourless protoplasmic bodies called *leucoplasts*, or *amidoplasts*. In the cells of deep-seated organs these lie in wait, as it were, for the sugar that travels from the leaves.

Protein Formation.

Very little is known about the formation of proteins in leaves. Nitrates and sulphates absorbed in solution by the roots either reach the leaves directly or are, to some extent, decomposed as they pass up the stem. The result in either case is that nitrogen and sulphur, in some form, reach the assimilating cells of the leaf and enter into combination with soluble carbohydrates. Possibly simple nitrogenous substances are formed and travel in a soluble form to the storage organs, where they are further synthesised, so that complex proteins result.

When the reserve food in a Potato tuber is tested the great bulk is proved to be starch. By using Millon's reagent, or employing the nitric acid test, it is seen that the greatest quantity of protein is stored just within the skin (p. 387).

By applying the various reagents, the nature of the reserve food in underground storage organs can be demonstrated.

The Carbon, Nitrogen, and Sulphur Cycle.

The substances that a plant uses in the building-up of complex materials are merely, as it were, a loan. When the plant dies the products of its general decomposition are returned to earth and air. Carbon dioxide is restored to the air, ready for future use. Compounds of nitrogen and sulphur are restored to the soil, because certain soil Bacteria control a chemical reaction that is by no means understood, but which results in the re-formation of nitrates and sulphates (p. 440).

Thus there is a never-ending cycle of exchange, and the substances needed for the upbuilding of plants are never wasted or destroyed.

In the tuberous root of the Dahlia the stored carbohydrate is *inulin*, a substance of the same chemical formula as starch. Inulin is also the reserve in the tubers of Artichokes.

Cellulose, a carbohydrate of the same numerical formula, occurs as a reserve in certain seeds (p. 398).

Carbohydrates and protein do not constitute the whole of food reserves, for fats and oils occur, more particularly, in seeds (p. 397).

The changes in chemical composition leading to the accumulation of reserve food supplies do not depend upon the direct action of light.

In the work of carbon assimilation the seven rays of the solar spectrum that make up the white light of day do not play equal parts in controlling synthetic food-production.

Chlorophyll and the Action of Light.

When light passes through a glass prism it is so split up in the passage that the white light that enters the prism escapes from it as seven coloured bands: red, orange, yellow, green, blue, indigo, and violet.

When, by means of suitable apparatus, these rays are made to pass through chlorophyll, the spectrum shows certain dark bands. There is in the chlorophyll-spectrum a particularly dark band replacing the red band of the light-spectrum. This dark band is an *absorption band*. The red rays have been absorbed by the chlorophyll instead of being allowed to pass through it and escape.

They are trapped by the chlorophyll apparently, to supply the greater part of the energy needed in the work of photosynthesis. That red light does induce starch formation is quite simply shown by growing a plant in a large-sized box fitted with a red glass front. When its leaves are tested they are found to contain a great deal of starch. On the other hand, very little starch is found in the leaves of a similar plant grown under similar conditions, but with the red glass replaced by blue.

Indirectly, by showing that a plant makes no starch in the absence of carbon dioxide, it has been proved that leaves must take in carbon dioxide in the photosynthetic operation.

The Escape of Oxygen.

The output of oxygen during the process can be proved directly by using a water plant. A water plant is chosen because it will go on behaving normally when the whole apparatus is put under water, so that the escaping oxygen may be collected by the usual laboratory method of displacement of water.

For this purpose nothing is better than Elodea Canadensis, the Canadian Pondweed.

Bits of the plant are put into a beaker of water that stands in a cylinder of water. A funnel is inverted over the beaker and a test-tube full of water is inverted over the stem of the funnel and clamped in position. The whole apparatus should be put near the sunniest window of the room. Bubbles of gas are seen to be given off from the leaves. They rise up the water in the stem of the funnel and, passing into the test-tube, displace a small volume of water (Fig. 175). The passage of bubbles almost ceases on a dull grey day. It is very rapid in bright sunshine when photosynthesis is active. But, at its best, it takes quite a long time, possibly a fortnight or even more, for all the water in the test-tube to be displaced. When the test-tube is quite full of gas a glowing splint introduced into it bursts into flame. This proves the gas to be oxygen.

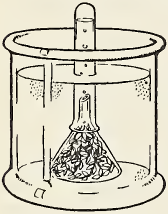


Fig. 175.—Experiment to show the evolution of oxygen in carbon assimilation.

To sum up: In photosynthesis, or carbon assimilation, a plant absorbs carbon dioxide from the air and returns oxygen. The process is carried on in the green parts of plants and is dependent upon light. This particular gaseous interchange, therefore, only takes place in the daytime.

Respiration.

Respiration, on the other hand, which involves the taking in of oxygen and the giving out of carbon dioxide, is just as active by night as by day.

To prove that in respiration a green plant gives out carbon dioxide, it must be kept in the dark. If it remains in the light the leaves take back the carbon dioxide that is exhaled and use it in their assimilatory processes. If, however, a potted plant is put into a black box or under a bell-jar in a dark room, and if a test-tube of lime water is also put in the box or under the bell-jar, the lime water turns milky in the course of a day.

Exhalation of Carbon Dioxide.

Thus half the gaseous interchange of the respiratory process, the giving out of carbon dioxide, is proved.

The other half, that is, the intake of oxygen, can be proved indirectly, as in the case of the root (p. 254), by bringing about the death of the plant.

Inhalation of Oxygen.

Again two Fuchsia plants can be used, each under a separate bell-jar. Under one of the bell-jars there is also a beaker of pyrogallic acid.

Just at first the plant carries on the work of photosynthesis. The oxygen it gives out in the process, as well as that originally within the bell-jar, is absorbed by the pyrogallic. There is, therefore, no available oxygen for use in breathing. Intramolecular respiration may prolong the life of the plant somewhat, but ultimately it dies from actual suffocation.

In the control experiment the plant grows healthily. Its leaves are taking in oxygen and giving out carbon dioxide in breathing. They are taking in the carbon dioxide and giving out oxygen in photosynthesis. Thus there is a perpetual cycle of interchange.

For a considerable period plants grow well under such conditions. Ferns in a glass case are generally very healthy. It is, however, necessary to admit air from time to time, because the volumes of gases taken in and given out in the two physiological processes do not exactly coincide. Also the saturated condition of the air is bad. Not only does it ultimately interfere with absorption from the soil, but it also provides an environment favourable for the intrusion of unwanted fungal growths.

In plants there is no elaborate provision for the discharge of waste, but, in addition to the carbon dioxide given off by all parts of the plant-body in respiration, surplus water is expelled through the stomata of the leaves in *transpiration*.

Two gas-jars, wax, and a well-fitting cork is all the apparatus needed to demonstrate transpiration.

Transpiration. A small branch of Lime, or other leafy plant, passes through a hole in the cork into a gas-jar containing water. In this case the waxing of all connections is to prevent evaporation of the water in the gas-jar. To make assurance doubly sure the water may be capped with a film of oil. A second and perfectly dry gas-jar is then inverted over the branch.

Drops of water collect on the sides of the upper gas-jar. This water must have come from the leaves, because evaporation from the lower gas-jar has been made impossible. It must have escaped in the form of water vapour, because it is not seen until drops condense and collect on the sides of the jar.

A modification of this experiment serves to demonstrate that the leaves give off only pure water. If a coloured solution replaces the water of the lower jar, *colourless* drops of water still accumulate on the glass of the upper jar.

If the apparatus is at once put into the dark, there is practically no condensation of water in the upper jar. Stomata close in the dark, therefore transpiration ceases during the night.

To see whether or no water really comes from the leaves it is only necessary to cut them off and then invert the dry gas-jar over the bare twig. It is well to vaseline the wounds first, to prevent the evaporation of water from the cuts.

As, in most leaves, stomata are much more numerous on the under than on the upper surface, it is reasonable to suppose that transpiration will take place most actively through the lower epidermis.

Accurate comparative measurements may be made by using spring balances and suspending from each a Laurel, Lime, or other fairly large leaf.

One leaf is smeared with vaseline on both surfaces. Another on the lower surface only. Another on the upper surface. A fourth leaf is left in its natural state.

The weight is carefully noticed in each case at the beginning of the experiment. The initial weight changes quickly in the case of the fourth leaf because it loses water rapidly. The loss of weight is just a little slower in the third leaf. The second has the mouths of its actively transpiring surface blocked with grease and therefore loss of weight can only take place very slowly, as a result of extremely slow transpiration from the upper surface. The first leaf, greased on both sides, keeps a constant weight.

This experiment gives accurate comparative measurements, but if spring-balances are not available, the leaves, variously greased, may just be allowed to lie on a sheet of paper or glass for several days, the changes being judged by the eye.

Naturally, external conditions play a large part in determining the rate of transpiration. A good drying-day for clothes is also a day on which transpiration is active.

The Effect of Dry Air on Transpiration.

The influence of a dry atmosphere in increasing the rate of transpiration is seen by putting two similar leafy twigs under separate bell-jars, whose vaselined rims rest on glass plates, so that no air enters from without. In one case a basin of calcium chloride accompanies the twig. The effect of calcium chloride is to remove every trace of moisture from the limited supply of air. In this dry atmosphere the leaves gradually give off all the moisture they contain. They are so dry that they can be crumbled to a fine powder.

The leaves under the other bell-jar are still fresh and green. They have given off water vapour until the air has become saturated with moisture. This point reached, they could give off no more. In the damp atmosphere, therefore, transpiration has been brought to a dead stop.

Influence of Environment on Transpiration.

The influence of external conditions on transpiration can be accurately determined by making use of the apparatus that served to measure the rate of root-absorption (p. 250). A cut branch must be substituted for the whole plant. By putting the apparatus under different conditions the influence exerted by sun, cold, wind, darkness, and humidity can be compared.

It would seem that the activity of the leaves in transpiration must cause water to travel up the stems. This does appear to be the case and may be demonstrated by putting two twigs, as nearly alike as possible, in test-tubes of equal volume containing water capped by a layer of oil, to prevent surface evaporation. The leaves are cut from one twig and the cut surfaces of the stem covered with vaseline.

The Pull of the Leaves.

The comparative rapidity with which the water level drops in the tube that holds the leafy twig is most marked. By the time the end of this twig is merely resting in a drop of oil, the other test-tube still contains almost all the original volume of water.

The leaves of the leafy twig have been instrumental in drawing water up the stem and passing it on to the outside air, so that finally they have emptied the test-tube.

It may be, then, that leaves do help to control the ascent of sap in plants. That they cannot, by any means, be indispensable factors is seen in the rapid rise of sap in trees in spring-time, when the leaves are still folded in the buds.

As the whole work of leaves depends upon their relation to the air, the stems that bear them grow in such a way as to bring them into this relation in the best possible way.

Leaf-mosaics.

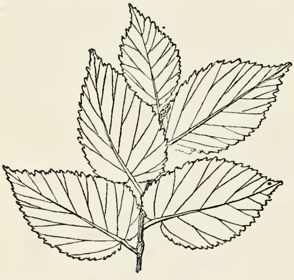


FIG. 176.—Leaf-mosaic in Elm.

Most leaves are *diageotropic*, that is, their blade is parallel to the ground. It is interesting to notice in the leaves of creeping and climbing plants, as well as in the foliage of trees, how little overlapping there is. Each leaf is given a good chance to carry on its work. Little leaves fit into spaces between larger ones. Such a *leaf-mosaic* is beautifully seen in the young branches of Ampelopsis and in the Ivy. Branches of Beech and Elm also illustrate this point well (Fig. 176).

It is possible that the individual differences in the form of foliage leaves may have arisen in response to this need for a good place in the light and air. Be that as it may, leaf modifications are manifold. One definite morphological difference in foliage leaves is that some are *simple*, whereas others are *compound*.

In a simple leaf the *blade*, or *lamina*, is in one piece.

Simple Leaves.

In a Lilac leaf the edge of the blade, that is, the *margin*, is *entire*. It is an uninterrupted border outlining the shape of the leaf (p. 304).

In the Aspen (White Poplar) leaf the margin is *crenate*, having rounded teeth.

The Birch, Deadnettle, and Stinging Nettle have a saw-like, or *serrate* margin (Fig. 207).

The margin of the Dandelion is *dentate*, being cut into prominent teeth (Fig. 182).

In the Holly the teeth are still more prominent because they are rigid. Such a margin is *spiny*.

In the Oak there is more than a mere irregularity of the margin. Deep indentations cause definite *lobes*.

In the Chrysanthemum the lobes are more irregular and very much deeper. Deep as they are, they do not reach the midrib, and the leaf is still simple.

The blade of a simple leaf may be attached to the axis that bears it directly, without the intervention of a petiole. The leaf is then said to be *sessile*, or sitting upon the main stem. More commonly the leaf is provided with a petiole which determines very largely the angle made with the axis. In the angle formed between leaf and axis a bud develops.

Compound Leaves.

In a *compound* leaf the blade is cut up as far as the midrib, so that a number of leaflets make up one leaf. All compound leaves are petiolate, and in the angle that the leaf-stalk makes with the axis a bud is developed. Here is the proof that no matter how many *leaflets* there may be in the compound leaf, there is only one *leaf*, with an axillary bud at its base.

Palmate.

It has already been seen that the leaflets of the Horse Chestnut extend somewhat like the outstretched fingers of a hand. It is for this reason that the leaf is said to be *palmate* (Fig. 146). Seven is a very general number for the leaflets in this case. The very large leaves may have as many as nine, and the smaller ones five or even three. Another palmately compound leaf is that of the Lupin; here the leaf is stipulate.

The commonest form of compound leaf is that in which the leaflets are disposed in pairs along the midrib of the leaf. As there is some resemblance to the form of a feather in this arrangement, the leaf is said to be *pinnate*, from the Latin *pinna*, a feather.

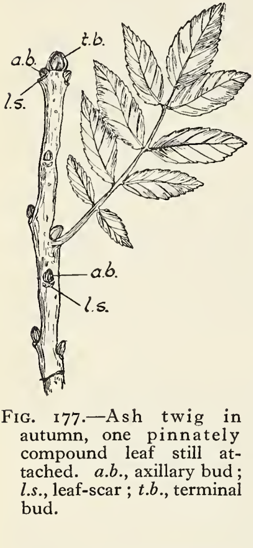


Fig. 177.—Ash twig in autumn, one pinnately compound leaf still attached. *a.b.*, axillary bud; *l.s.*, leaf-scar; *t.b.*, terminal bud.

Pinnate.

The Rose and Caragana have pinnately compound leaves, and so has the Ash (Fig. 177). In the latter the compound leaves grow on the twig in alternate pairs, but the members of a pair are not exactly opposite one another. The young part of the stem that bears the foliage leaves is curiously flattened. The first pair of axillary buds is very close to the terminal bud and all the buds are black. It is just possible that the tree owes its name to the sharp contrast that the ashen grey stem makes with the coal-black buds that grow upon it.

The pinnately compound leaf of the Rose has two stipules at its base which are *adnate* (Fig. 163, C); they are attached for the whole of their length to the leaf-stalk.

In the stipulate and pinnately compound leaf of the Sweet Pea all but the lowest pair of leaflets are modified to form tendrils (Fig. 163, A). Vetches, Vetchlings, and other Canadian Legumes should be examined.

Ternate.

When a compound leaf is made up of three leaflets it is *ternate*. Strawberry, Wood Sorrel, Prairie Bean, and Clover all have ternately compound leaves (Fig. 160).

Sleep Movements of Leaves.

The *sleep movements* of the ternate leaves of many members of the family Leguminosæ, and of the Wood Sorrel, prevent transpiration from taking place too actively when loss of water would be a disadvantage to the plant, as in the cool of the evening or in great heat.

In the White Clover the stomata are most numerous on the upper surfaces of the leaflets, therefore it is these surfaces that the sleep movement is designed to shield.

The two lateral leaves droop forward in such a way that their upper surfaces meet. The terminal leaflet then bends over them, roofing them in as it were (Fig. 178, A).

The sleep movement is different in the Wood Sorrel, because here the stomata are chiefly on the lower surfaces.

As night draws on a downward and backward droop of the leaflets brings the midrib of the underside of each leaflet up against the leaf-stalk. Each leaflet then bends along its midrib so that one half of the under surface of each leaflet, where the stomata are numerous, is in close, flat contact with one half of the under surface of its neighbour (Fig. 178, B).

A little paper-cutting and -folding will make the procedure in these two cases very plain.

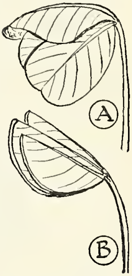


FIG. 178.—Sleep movements of foliage leaves. A, White Clover. B, Wood Sorrel, final position.

In Clover and Wood Sorrel the tropism is a response to the stimulus of light. The mechanism of such movement in leaves is by no means understood. It is apparently controlled by the *pulvinus*, a somewhat swollen basal portion of the leaf-stalk. It may be that a loss of turgescence in one half of the pulvinus causes the fall of the leaflets in the sleep movements. A recovery of turgescence in this region and a loss of turgescence in the other half of the pulvinus would then bring the whole leaf back to its normal, outspread diurnal position.

The movements of these leaves are *periodic*, occurring as regularly as the alternation of day and night. Similar movements in the leaves of the Sensitive Plant are induced by contact.

Movement in connection with Growth.

A response and a mechanism similar to those of the Clover and the Wood Sorrel must determine the movement of a leaf during its growth period, the ultimate result being that its petiole has formed such an angle with the stem that bears it, that it is rightly placed with regard to the direction and intensity of light. Hence the formation of leaf-mosaics.

In some very specialised cases leaf movement occurs in connection with feeding, when the plant supplements its normal inorganic food supply by absorbing the soft tissues of animal organisms.

Movement in connection with Feeding.

In Central Canada there are four genera of Carnivorous (Insectivorous) Plants; Pinguicula, the Butterwort; Drosera, the Sundew; Utricularia, the Bladderwort; and Sarracenia, the Pitcher-plant.

In all there is provision for the digestion and absorption of certain animal tissues, and it is always the leaf that functions as the trap.

Then again, all Carnivorous Plants have this in common: they grow in habitats markedly deficient in nitrates. It would seem that the carnivorous habit has arisen in response to the need for a supply of nitrogenous food, to make up for the lack in the soil in which they are rooted.

The Butterwort grows in boggy places, but is not very commonly found in our region.

The Butterwort.

The formation of nitrates in soils depends very largely upon the action of Bacteria (p. 440). In boggy areas there is so little available oxygen that bacterial activity is hindered. It is for this reason that the soil suffers a nitrate-poverty.

The Butterwort, growing in such a habitat, has its somewhat trough-like foliage leaves arranged in the form of a rosette, in the centre of which rises a delicate stalk, bearing a single flower which is of a bluish-violet colour (Fig. 179, A).

The edge of each foliage leaf is just slightly upturned and its surface is rather sticky, owing to the secretion of a mucilaginous substance from numerous glands dotted all over it. It is estimated that there are about 25,000 of these glands on one square centimetre of the leaf.

When small flies alight on the leaf it becomes still more trough-like. Its edges fold slowly inwards and the captives are pushed more and more towards the middle of the leaf. At the same time the mucilage is not only flowing more freely, but its character has changed. It now shows a definite acid reaction and digests the protein with which it comes in contact. The mucilage is, in fact, similar to the gastric secretions of the animal stomach (p. 155).

It is interesting to note that the actual digestive juice cannot be induced to flow by mere contact. A grain of sand, for instance, produces no result. If, however, a minute piece of lean meat, or of cheese, is dropped upon a Butterwort leaf the discharge of mucilage increases in volume and its character slowly changes. When the process of digestion is complete the excess of mucilage and acid is reabsorbed by glands of the leaf, along with the digested food.

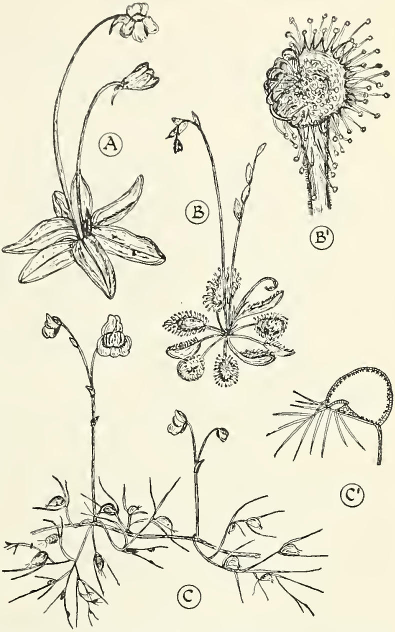


FIG. 179.—Insectivorous plants. A, Butterwort. B, Sundew. B^1, One leaf of Sundew, with infolding tentacles. C, Bladderwort. C^1, Diagram of one bladder in section.

The Sundew also occurs in boggy areas, being rather common on mossy banks in muskegs.

The Sundew. The plant takes its name from glistening red tentacles that project from the upper surfaces of the foliage leaves, which are arranged in a basal rosette.

The slender tentacles are club-shaped at the free end, where a glistening, honey-like drop of mucilage is secreted. It is these dew-like drops that attract the prey to the leaves (Fig. 179, B).

The capture is effected by a slow inward bending of the tentacles, one after another, in a clock-wise direction. Contact with an inorganic substance induces a slight response in some of the tentacles, but the movement is by no means general, and the responding tentacles quickly right themselves. The contact of an insect, or of the smallest particle of any organic substance, causes not only the movement of the tentacles but, at the same time, a free flow of glistening liquid which contains an enzyme and a weak acid. To hold the captive and the digestive secretions the leaf itself generally becomes slightly concave.

The digestive fluid acts upon the organic substance and the products of digestion are absorbed by the leaf. The hard parts of an insect, the wings, legs, eyes, and stomach, remain on the leaf-surface. When the process of absorption is complete the leaf is found to be quite dry. The advantage of this is that the hard, undigested parts lie loose on the leaf-surface, and are washed away by rain and blown away by wind. Freed from their hampering presence, the field is prepared for further action. Once more the tentacles exude their glistening drops to lure other victims to their doom.

The Bladderwort. The Bladderwort is a submerged, rootless water plant, with finely divided leaves which carry on the work of photosynthesis, making use of the carbon dioxide dissolved in the water in which the plant grows. Certain parts of the leaves are curiously modified to form bladders, and it is their work to supply the necessary nitrogenous compounds (Fig. 179, C).

The opening into the bladder is guarded by a flap suspended from the upper border. Its lower edge rests on a small pad of tissue in such a way that the flap responds at once to pressure from without, whereas pressure from within closes it all the more firmly. Projecting from the neighbourhood of the mouth there are stiff, branching hairs.

Cyclops, or Daphnia, possibly fleeing from a young newt, make for safety among the hairs. Slight pressure on the valve gives them an entry into the bladder. They have escaped death in one form only to meet it in another. The bladder is lined with glands whose secretions digest the captive. Ultimately the products of digestion are absorbed by the tissues of the leaf.

A species of Bladderwort with conspicuous yellow flowers and relatively large bladders is commonly found in small sloughs of the poplar region.

Dimorphic Leaves of Water Crowfoot.

Dimorphic leaves, that is, leaves of two forms, occur in various other water plants, for example, certain of the Water Crowfoots (*Ranunculus Purshii* and related species). The floating leaves have a cuticularised epidermis on the upper surface to prevent excessive transpiration. The submerged leaves are very finely divided. This modification is a great advantage to a plant growing in stagnant water. The slightest ripple in the pond changes their position, so that they are brought into contact with a different volume of water. This gives them a fresh source of supply of carbon dioxide for photosynthesis and of oxygen for breathing.

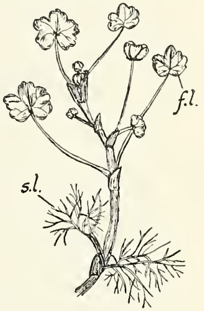


Fig. 180.—Water Crowfoot, showing two forms of foliage leaves. *f.l.*, simple floating leaves; *s.l.*, finely divided, submerged leaves.

Movement determined by Humidity.

Dimorphic leaves also occur in the Water Parsnip when this species develops with its basal leaves immersed in water.

Leaf movements in Clover are made in response to light.

In the Sundew they are induced by contact of a special kind. In some *xerophytes* leaf movement is determined by the hygrometric condition of the atmosphere. If the air is dry the leaf folds in some way. In a moist atmosphere it expands.

As its name implies, a xerophyte is a plant that grows in a dry situation (Greek *xeros*, dry ; *phyton*, a plant).

Xerophytes.

The disadvantages under which xerophytes labour are two-fold. In the first place they grow in situations where there is such scarcity of water that they have difficulty in absorbing enough for their needs. In the second place, as they are without shelter, exposed to the full force of sun and wind, there is every inducement for them to part with the water which they have, with so much difficulty, secured.

The disadvantage as regards absorption is got over to some extent by the possession of unusually long tap-roots. The tap-roots of Thistles are often as much as, or even more than, six feet in length.

In some cases, too, the plant is its own storehouse of water, conserving in its leaves or stems a water supply that makes the scarcity in the soil of less importance.

Water Storage.

In House-leeks and Stonecrops that grow on rocks and walls, water is stored in the leaves. On pressure a drop of water is readily squirted from a fresh Stonecrop leaf.

In the numerous Cactus varieties, water is stored in the stems. The Purple or Cushion Cactus and the Prickly Pear are common on the arid plains and hillsides of Western Canada.

The contrivances to ensure reduced transpiration in xerophytes are manifold.

Reduction of Leaf Surface.

As water is given off from the foliage leaves it is obvious that reduction of these would be a ready means of limiting the rate of transpiration.

The most drastic reduction would be to dispense with foliage leaves altogether and let some other part of the plant concern itself with photosynthesis.

This is exactly what has happened in the Butcher's Broom (Fig. 166, A), where the leaf-like axillary dwarf branches have taken on the work of assimilation. In the Cactus, stems of various shapes manufacture the carbohydrates and proteins, and bear leaves that are very much reduced.

1—Suppression of Foliage Leaves.

A leaf that is horizontally extended will, other things being equal, give off much more water than one that exposes only a small surface to the light and air. It is therefore an advantage for the foliage leaves of a xerophytic plant to depart from the typical laminate shape.

2—Modifications in the Shape of Leaves.

Thus in the Gorse the leaf is short and cylindrical in shape (Fig. 166, C). An accessory modification is found in the assimilating ridges of the stem. Similar ridges occur, too, in the Broom, where the foliage leaves are much reduced in size (Fig. 254).

In the Pine, although the foliage leaf is long, it is very narrow and thick (Fig. 166, D). Its epidermis is cuticularised as an added protection against undue transpiration, and the stomata, through which the leaves transpire, are sunk below the level of the general epidermis. The cells that flank each stoma arch over it slightly, forming a minute vestibule into which water vapour from a stoma escapes. Thus the air in this very limited area is saturated with moisture, with the result that further transpiration from the leaf is delayed to some extent. A similar type of leaf is found in the Spruce.

In Heather not only are the foliage leaves very small and closely packed, but the blade of the leaf is rolled so as to enclose a hollow chamber (Fig. 181, B). It is in the epidermis lining this chamber that the stomata occur. The stomata occupy a similar position in the Crowberry, which is found in Canadian muskegs.

3—Rolled Leaves.

In all these cases the reduction in the size of leaves is permanent. A temporary reduction, determined by external conditions, takes place in some cases, and is due to the folding of the leaf.

4—Temporary Reduction of Surface.

The grass that covers the sand-dunes of many coasts is a good example of such folding. This grass, the Sea Marram, or Psamma, has a very long blade which is grooved lengthwise. In these grooves the stomata lie. In wet weather the grass blade is flat and strap-like. On dry days the blade curls inwards on either side of the middle line of the leaf, forming a hollow cylinder. It folds in such a way that the stomata, which are on the upper surface of the leaf, are within the cylinder, and hence protected from sun and wind (Fig. 181, A). It is when the leaves are in this rolled condition that, in walking over the dunes, one's legs are constantly pricked by the sharp tips of the rolled blades.

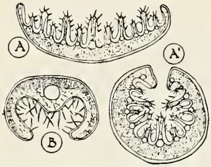


Fig. 181.—A, Diagram of transverse section of a blade of the Marram grass (Psamma) in wet weather. A¹, The same on a sunny day. There is a vein at the base of each ridge, and the stomata are in the curves of the grooves. B, Diagram of transverse section of a leaf of the Cross-leaved Heath (permanent shape). A vein occupies the centre of the blade. The stomata are among the hairs.

Such leaf-rolling is characteristic of many grasses. It depends upon the presence of hinge-cells at the bases of the grooves. These regulate the infolding of the leaf by losing their turgidity. In regaining turgidity they cause the blade to flatten out.

It is a similar response to conditions of moisture that makes the " Rose of Jericho " an object of interest. Its branches, which are consistently curled inwards, change their position and bend outwards when the plant is put into a saucer of water.

The Development of Cuticle.

When a branch of Beech, whose buds have just opened, is picked, the delicate fringed Beech leaves droop in a very short space of time. The epidermis covering their surfaces is so thin that transpiration is taking place through this layer of tissue as well as through the stomata. Later the outer walls of the epidermal cells are cuticularised, that is, a layer of *cutin*, in many respects resembling cork, forms over the cellulose wall. Such cuticularisation hinders transpiration from taking place through the whole epidermis and helps to limit it to the stomata only.

In many xerophytic plants the cuticle is developed in a high degree. The shiny leaves of evergreens owe their characteristic appearance to cutin.

The Presence of Wax.

Further defence against undue transpiration is provided for in some leaves by the overlaying of the cuticle with a coating of wax. This, commonly called " bloom," is seen at its best in the outermost layer of the fruit coat of the Plum, Apricot, and Peach.

Such a covering layer of wax is found on the epidermis of the leaves of Pinks and Carnations. Haberlandt, on carefully wiping off the wax from the leaves of the Swedish Turnip, found that they then lost 30 per cent. more water than when they were in their normal state.

The rate of transpiration, again, is reduced in leaves that are protected by a covering of hairs.

The Development of Hairs.

The large leaves of Coltsfoot have a dense mat of hairs on the under surface where the numerous stomata occur. The blocking of the stomata by still air entangled in the hairs, and by air saturated with water vapour, appreciably diminishes transpiration.

Other notably hairy leaves are those of the Cinquefoils and the Three-flowered Avens, which grow in dry places, and the silvery-white leaves of the Wormwood Sage which is so common on the prairie.

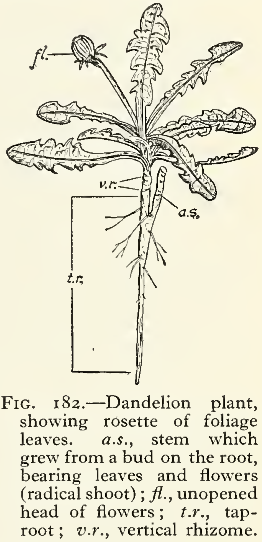


Fig. 182.—Dandelion plant, showing rosette of foliage leaves. *a.s.*, stem which grew from a bud on the root, bearing leaves and flowers (radical shoot); *fl.*, unopened head of flowers; *t.r.*, tap-root; *v.r.*, vertical rhizome.

Protection as a Result of Position.

Very frequently the actual arrangement of foliage leaves is a bar to rapid transpiration. This is true of radical leaves, that grow close to the ground in the form of a rosette (Fig. 182).

The upper leaves of the rosette of a Dandelion, growing by the roadside, are often seen to be withered, while those below them are healthy and turgid. The upper leaves have been sacrificed for the general good.

The shelter they have given has prevented excessive transpiration from the lower leaves of the rosette. The grooving of the individual leaves, as well as their arrangement, directs rain and dew to the region where the long tap-root is growing vertically downwards. Also, because of its contact with the soil, the rosette prevents some evaporation from the particular area it covers, which is, in consequence, not quite so dry as the rest of the ground.

The leaves grow from a short vertical rhizome above the tap-root. The reason why the rosette does not rise higher and higher above the ground level as the years pass is, that the branch roots of the tap-root, like the adventitious roots of rhizome, bulb, and corm, are contractile and, by their slight shortening, are able to maintain a constant relation between rosette and soil (p. 280).

In the leaf rosettes of many Thistles a still further protection against rapid transpiration is provided by a weft of delicate hairs, often superficially resembling a spider's web, which occurs in the centre of the rosette, more particularly when the leaves are young.

Experiments carried out on root-absorption showed that the power of roots to take up water diminished as the temperature dropped (p. 251). In Canada root-absorption ceases in the cold winter soil. If the leaves were actively transpiring at this time they would be losing water at a rate that would spell disaster. It is to prevent this that the leaves of evergreens (Holly, Pine, Spruce, Bog Cranberry) have such a strongly cuticularised epidermis.

Deciduous trees avert catastrophe by following a drastic course, and before winter is actually upon them they ruthlessly cast off all their leaves.

Leaf-fall.

The fall is by no means haphazard.

Certain cells at the base of the leaf-stalk become separated one from another, and so form an area of weakness. It is here that the leaf eventually breaks away. The veins of the leaf, continued in the petiole as vascular bundles, do not take part in this disintegration. It often happens, therefore, that the leaf hangs from the twig for a time supported only by vascular bundles and, possibly,

The Absciss Layer.

by the epidermis. The dividing layer, which is called the *absciss layer*, occurs also at the base of each leaflet of most compound leaves.

Either while the cells of the absciss layer are separating, or immediately afterwards, a formation of cork in this area heals what would otherwise be an open wound. Before the cork formation takes place there is an interchange of substances between the leaf and the branch that bears it. Any manufactured food that is still in the leaf passes along the bast of the veins to the leaf-stalk, and so to the branch where it is stored, probably just underneath the bark, in close proximity to the resting buds. The buds are able to draw on this reserve supply when they open in the spring-time.

Trees also make use of leaf-fall to get rid of waste materials. In plants, except for the giving off of carbon dioxide and water, there is no regular discharge of the waste products of metabolism. Unwanted substances do, however, pass into deciduous leaves before they fall.

If a branch is blown off, or hangs broken from a tree, its leaves wither and curl up, but they do not drop. This makes it clear that leaf-fall is a result of life, not death. It is the living protoplasm of the cells that controls the formation of the absciss layer and the deposition of the protective covering of cork.

Preparation for Winter.

By way of preparation, then, for winter, trees cast off their leaves, the fall being preceded by a safeguarding of food. Further, at the same time that a cork layer is forming over the leaf-scar, the lenticels in every part of the tree are being closed by a similar protective layer. Just as in any other hibernating individual, the dormouse, the hedgehog, or chrysalis, so in trees, the respiration will be at a minimum during the rest period of winter. In spring the thin cork layer of the lenticels crumbles, and they are functional once more.

In herbaceous perennials the preparation for winter, or for a seasonal rest period, consists in the complete dying-off of all parts that grow above the ground. Before this happens food travels from the leaves to be stored in the underground perennating organ, whether this be root, rhizome, bulb, or corm.

In annuals, as the plant dies completely, the only hibernation possible is in the form of seeds.

Biennials follow the herbaceous perennial plan at the end of their first year of life but, like annuals, stake their all on seed-formation at the completion of their second season.

In trees the beautiful autumn colouring that precedes the fall of the leaf is more easily seen because of the decomposition of chlorophyll and its ultimate disappearance. As a result of this the colours of other pigments, formed at this time, are plainly seen.

Autumn Colouring.

The most vivid colours occur when sunny autumn days are followed by frosts. The abrupt change from summer to winter conditions brings the work of the leaves to a sudden end.

In the sunshine, photosynthesis was active and sugar was produced in the leaves. The sharp night frosts put an end to this metabolic process, but the leaves retained their sugar. There is some connection between the presence of sugar in leaves and their red coloration.

The Sugar Maples of Canada have flaming autumn foliage. These leaves are very rich in sugar and, as they grow in a climate where warm and sunny days are followed by sharp frosty nights, all the conditions are perfect for producing the glorious colourings of the vivid Canadian " fall."

Contradictory though it seems, plants that grow in water or in damp marshy places, show many of the adaptations that occur in xerophytes for the reduction of transpiration.

Hydrophytes.

The sword-shaped leaves of the Iris are grooved and the sunken stomata are sheltered in the grooves. The leaves of the Sweet Gale are very small. The floating leaves of the Water Lily and Water Crowfoot are cuticularised. The leaves of the Osier Willow are silvery-white because of the hairs on their lower surfaces ; these surfaces in certain other Willows are coated with a deposition of wax. The Mealy Primrose (*Primula farinosa*), which grows in moist situations, takes its name from the unique nature of the leaves ; the white floury appearance of their lower surfaces is due to wax deposited in small rods or granules to protect the stomata ; the leaves, too, grow in the form of a rosette.

Such adaptations, obviously intended to regulate the output of water, indicate that even in water plants absorption is none too easy.

The fact is that damp earth is cold earth. In determining variations in the rate of root absorption (p. 251), there was seen to be definite loss of activity when the gas-jar was packed round with ice. Roots in a cold environment absorb slowly, and it is partly for this reason that precautions are taken to prevent excessive transpiration from the leaves.

Not only is damp earth cold, but it is also poor in oxygen. The roots are not breathing freely, and this is another hindrance to active absorption. Then, again, when boggy land dries in time of drought it becomes unusually hard, dry earth. At such seasons the xerophytic adaptations of water plants are a great safeguard against reduction of the plant's water content.

Halophytes.

In salt marshes, too, the ground is cold and poorly supplied with oxygen. More than this, substances in solution in the soil-water now hinder absorption. In the experiment just referred to it was proved that the addition of salt to the water in the gas-jar caused a great retardation of root-absorption, because the normal course of osmosis was interfered with.

Thus it is not surprising to find that plants growing in such situations also show marked xerophytic adaptations. The small leaves of the Saltwort are covered with fine down. In the very succulent Glasswort the leaves are mere scales (Fig. 183). The mealy appearance of the leaves in the Common Orache is due to protecting wax.

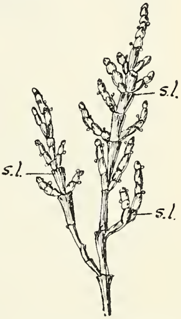


Fig. 183.—Glasswort. *s.l.*, scale-leaves, which are little more than ridges of the stem.

It has been suggested that in halophytes the stomata lose the power of closing. The water given off in transpiration is pure water (p. 314) ; substances in solution are left behind in the leaf. It may be, then, that in salt-marsh plants, small depositions of salt block the stomata, so that they cannot close.

If transpiration were very active in these plants the sap of the cells would, of necessity, become more and more dense, and the whole economy of the plant would thus be thrown out of gear.

Internal Structure of Water Plants.

The buoyancy of water plants depends upon their numerous, and often large, internal air-spaces. As well as making for lightness, the spaces store up air, in which oxygen and nitrogen are practically in the same proportion as in the atmosphere. It appears that the plant organs draw upon this supply in respiration, finding it easier to use the oxygen of their own store than that dissolved in the water. The air-spaces are very regularly disposed in root and stem, as may be seen by cutting across the axis of the Mare's Tail and looking at it with a lens (Fig. 184).

Another characteristic of the internal structure of water plants is the great diminution in the number of wood-vessels. In many submerged plants, as in the Grass Wrack, they are entirely absent. As water is taken in by all parts of the plant, well-regulated conduction is not necessary. In the Mare's Tail there is a need for wood-vessels, because the long stem projects far above the surface of the water, and solutions must be carried upwards to the leaves. In such cases, although they are present, the number of wood-vessels is very much reduced.

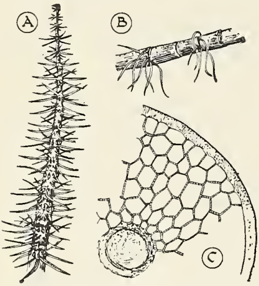


FIG. 184.—Mare's Tail. A, The axis above the level of the water, bearing inconspicuous flowers and small foliage leaves. B, The submerged rhizome, bearing adventitious roots that anchor the plant. C, Diagram of transverse section of B, showing the large intercellular spaces.

Hibernation of Water Plants.

Many floating water plants, in hibernating, retreat bodily to the floor of the pond in which they are growing. No Water Crowfoot is seen on the surface of the water in autumn.

In other individuals, while the great bulk of the plant dies away, definite buds are separated off, drop to the bed of the pond, and lie dormant until the following spring (Fig. 185). Buds are detached in this way in the Floating Pondweed and the Frogbit. Before they separate, food passes to the buds for storage. Sugar changes to starch, and it is the weight of the accumulated starch grains that makes the buds heavier than water.

In the spring there is a reverse change of starch to sugar. The tightly packed bud expands and grows and, in its growth, uses much of the reserve supply of food. As a result of this reduction in the stored carbohydrate, together with the expansion of the cells, the whole bud becomes so light that it rises to the surface of the water. The axis of the bud then elongates; axillary buds develop into branches, and the individual enters upon a new period of life.

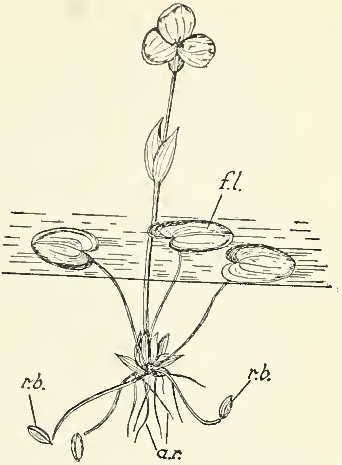


Fig. 185.—Whole plant of Frogbit.—*a.r.*, adventitious roots. *f.l.*, foliage leaf with cuticularised upper surface; *r.b.*, resting buds becoming detached.

CHAPTER XXIV

THE FLOWER

Relationships in Flowering Plants and their inclusion in Natural Orders, or Families, as they are now more generally named, depend entirely upon the structure of the flowers.

It may happen that all the plants of one family agree in their general morphological characteristics; all the plants in Cruciferæ, the Mustard Family, are, for example, herbs.

But this agreement is by no means the rule. There is very great diversity in the growth of the Clover of the meadows and the Caragana of the gardens; yet both these plants belong to Leguminosæ. The Cinquefoil, creeping as an insidious weed along the garden beds, the erect Apple tree, the shrubby Wild Rose, are all members of Rosaceæ; but structurally they are widely different.

In Flowering Plants it is on the flower, in the big majority of cases certainly, that the permanence of a species depends. The seeds that are developed give rise to new individuals so that the race persists. Certainly bulbs and corms, instead of seeds, are planted to flower in the garden beds. But in the course of time the Daffodils appear sparsely and the flowers dwindle in size; the Darwin Tulips lose the varied colour of their blooms, which become smaller and more insignificant each year. On the bulb farms of Holland especial care is taken to get good seeds from the various flowers. These are sown, and in three years' time they have formed new bulbs as a result of basal swelling of the leaves (p. 284). In this way weakening of the strain is prevented.

In Chlamydomonas and in Hydra, in the plant as well as in the animal, sexual reproduction depends upon two nuclei, from different sources, meeting and fusing. A similar fusion of two nuclei of diverse origin is the basal fact in the sexual reproduction of flowering plants. The male gamete is developed within a pollen grain; the female gamete is developed in an ovule within the ovary.

Pollination.

Speaking generally, the fertilisation of an ovule is dependent upon pollen from another flower. As the flowers are separated in space some agent must carry the detached pollen to the fixed egg-apparatus.

In Canada wind and insects are mainly responsible for such transference of pollen.

Insect Pollination.

The wind bloweth where it listeth, and it is in a more or less haphazard way that, through its intervention, pollen reaches the goal. Indeed, as far as the *transference of pollen* from one flower to another is concerned, there is no purposeful action even on the part of insects. Their visits have an aim, it is true, but the aim is in relation to their own immediate needs, and is in no way concerned with any good that may ultimately accrue to the plant.

Factors Determining Insect Visits.

Hunger is the most potent factor in determining the visits of insects to flowers. The food they find is nectar and pollen. In some quite exceptional cases they feed on the juice of succulent floral leaves ; bees pierce the blue perianth leaves of the Wild Hyacinth and suck the abundant juice.

1—Food.

Nectar is produced by special glands in the flower for the sole purpose of attracting insects. Strictly speaking, it is only " honey " after it has been operated upon by a bee. The change from *nectar* to *honey* takes place in the bee's mouth, where salivary secretion brings about the change. The nectar of the flower is a dilute solution, consisting, approximately, of 75 per cent. water, and 25 per cent. cane-sugar ($C_{12}H_{22}O_{11}$) and grape-sugar ($C_6H_{12}O_6$) in equal proportions. In honey there is only about 20 per cent. of water, and of the 75 per cent. of sugar present, only about 2 per cent. is cane-sugar. There are also, in honey, certain organic acids. Speaking freely, however, it is very usual to talk of " honey " and " honey glands " in the flower.

The position of nectaries is different in different flowers, but is always such that an insect, inserting its proboscis to draw up the honey, plays, all unwittingly, an important part in *pollination*, which precedes *fertilisation*.

Pollen develops in floral leaves called *stamens*. It is essential for the maintenance of the species ; its use as insect food is incidental. In such insect-pollinated flowers as have no honey-glands there are usually many stamens, producing an abundant supply of pollen, above and beyond the plant's own need. This is the case in Poppies and Roses.

A delicate thermometer shows that the temperature in the centre of a flower is slightly higher than that of the air outside.

2—Shelter.

For this reason insects that have no home of their own seek shelter in flowers during a temporary cold or damp spell. On late summer or early autumn mornings earwigs are found between the pink or white sepals of the Japanese Anemone, in the spur of the Garden Nasturtium, and among the many flowers of the Dahlia head. They have been sheltering from cold and damp all through the night. The flower has been their casual ward.

Again, but this is not so common, some insects visit flowers in order to lay their eggs within the ovaries. It is a wonderful instinct that leads to the deposition of the animal eggs among the ovules of the plant. When the insect larvæ hatch out they find themselves surrounded by an abundant supply of food, for the ovules have now become seeds. Here again the provision is ample for the needs of both organisms. The number of seeds is such that after the larvæ have eaten all they need, many still remain to fall to the ground and germinate.

3—Egg-Laying.

This particular relation between insect and plant is beautifully illustrated in the interdependent life-histories of the Nottingham Catchfly and some of the Owlet Moths. The flower is one of the wild Pinks of England, and its distribution is very local. There are certain districts in Cambridgeshire and Norfolk in which it may be found, and it grows near Dover also.

The Nottingham Catchfly.

Its flowers, like those of the Tobacco plant, Evening Primrose, and Night Scented Stock, appear colourless and faded during the day. An hour or so before sunset they not only open out but they are, at this time, very sweetly scented.

The time of their expansion coincides with the nocturnal flights of moths. The Owlet Moth is attracted to the Nottingham Catchfly by the starry whiteness of the petals, the abundant honey at their base, and the sweet smell. Male and female moths alike visit the flowers for food, their long probosces enabling them to reach the honey. Their visits probably result in some transference of pollen from one flower to another, but the process is haphazard as they are inconstant visitors.

There comes a time, however, when the relation between the female moth and the flower is much more intimate. Her under surface is covered with pollen from younger flowers that she has visited for honey. She now rests upon an older flower, where the stamens are withered, for a considerable period. She pierces the ovary wall with her ovipositor and lays her eggs within the ovary. The under surface of her body rubs against the stigma of the flower in such a way that much of the pollen she carries is left upon it. Her life-work done, she flies away, and shortly afterwards she dies.

The pollen deposited by the moth upon the stigma of the flower brings about the fertilisation of the ovules in the ovary, and they become seeds.

The eggs of the Owlet Moth hatch out and the larvæ feed upon some of the seeds that they find in their temporary home.

The instinct of the mother moth has led her to provide for her offspring by putting her eggs in the most favourable situation possible. All unwittingly, she has, at the same time, benefited both the plant and her offspring by bringing about pollination, and so ensuring the formation of seeds.

In August the fruit opens and the seeds are scattered. A little before this the larvæ have bored their way out of the fruit and have spun down to the ground, where they change into the chrysalis stage just below the level of the soil. Seeds and chrysalids pass through a long rest period, for it is not until the following year that the seeds germinate and produce new plants, and the chrysalis coat bursts and the Owlet Moth emerges. In June the new Nottingham Catchfly is in flower and the new Owlet Moth is poising on its scented petals.

The Stamens.

The stamen in which the pollen is produced is a leaf that has become, in the course of evolution, especially modified for this particular work of pollen bearing.

The pollen develops in tubular cavities that run the length of the very obvious head of the stamen. This head is called the *anther*, and is generally supported on a slender stalk, which is the *filament*. Between the lobes of the anther is the *connective*. In it is a vascular bundle which carries water and food to the developing pollen.

The Pollen Grain.

Pollen consists of hundreds of minute grains, each one of which is an independent cell. The cell-wall is two-layered. The outer coat is thick, but in it there are numerous thin places. The inner wall is extremely thin. The nucleus of the pollen grain divides, and two of the nuclei resulting from the divisions are the male gametes, destined to reach an ovule in the ovary.

The Carpels.

The ovary containing the ovules is the basal part of a *carpel*, another specially modified leaf. The upper parts of this leaf are designed to bring about the safe conduct of male gametes from the pollen grain, to the female gamete that rests passively in each ovule. To this end a stigma and a style surmount the ovary. The *stigma* is projected upwards so that it may be in the best possible position for receiving pollen. The *style* is then necessary to act as a means of communication between stigma and *ovary*.

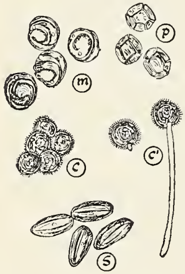


FIG. 186. — Various forms of pollen grains, showing thin places in the outer coat of each. *c.*, Canterbury Bell; c^1., the same, germinating; *m.*, Musk; *p.*, Pink; *s.*, Sage.

Fertilisation.

The stigma is usually somewhat sticky, or hairy, or uneven in surface. The advantage of this is that, once pollen grains are carried to it by wind or insects, they are held in position. The outer coat of most pollen grains is somewhat sculptured, so that it, too, helps in setting up a frictional contact (Fig. 186).

On the stigma the pollen grains absorb moisture to such an extent that the internal pressure is more than the outer wall can support, and it bursts at one of the thin places. But this is not all. As a result of the pressure the thin inner wall pushes through the gap as a short tube. The whole proceeding is analogous to the collapse of a weak place in the outer tyre of bicycle or car. In this case, too, the thinner inner tube bulges through the gap.

The pollen grains now lie on the stigma, each with a little tubular projection, but the gametes they produce are still far from the waiting egg. To bring them into contact the short tube that emerges from each pollen grain, grows through the tissue that separates the stigma from the ovary.

The *pollen tube*, or *pollen thread*, secretes enzymes at its tip. These break down the cellulose walls of the tissue of the style and aid the pollen tube in actually absorbing the contents of the cells. Thus the pollen thread feeds as it bores onwards, and it is the food thus obtained that gives it the energy it needs for growth. As the pollen tube grows on, two male gametes are seen near its tip. Eventually the style is riddled by elongating threads from various pollen grains. They have made their way from the stigma at the apex to the ovary at the base.

In the coat of each ovule there is a minute gap called the *micropyle* (Greek *micro*, little ; *pyle*, a gateway). The pollen threads are chemically attracted to these holes, and the tip of a pollen thread enters each micropyle. It thus carries the two male gametes right into the ovule. An opening at the tip of the tube now allows the gametes to escape and one of them fuses with the egg-cell of the ovule.

It sometimes happens in fruits, in a pea pod for instance, that one ovule escapes fertilisation. It has possibly grown a little during the development of the fruit, but it has not become a seed. It is small and shrunken-looking, and if it were put into the ground no new plant could grow from it.

The leaf, then, that bears the ovules has, speaking generally, three parts : the stigma, the style, and the ovary. Such a leaf is called a carpel. In the flower the carpels always occupy the central position, for they grow on the extreme apex of the flower stalk, which is, in this upper part, called the *receptacle*.

The Pistil, or Gynœcium.

In some carpels the style is so short as to be almost non-existent. This is the case in the Buttercup. The stigma here is somewhat hooked, and passes, almost immediately, into an expanded ovary, containing only one ovule.

Free Carpels.

There are many carpels clustered together at the apex of the receptacle of the Buttercup, and, all together, they are known as the *pistil*, or *gynœcium* (Fig. 187, A). The latter name indicates the special function of this part of the flower, for it is derived from the Greek *gyne*, a female; *oikos*, a house, and signifies the female part of the community.

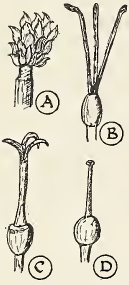


Fig. 187.—Different forms of gynœcium (pistil). A, One pistil of the Buttercup: made up of many free carpels. B, One pistil of the Bladder Campion: made up of three joined carpels, whose styles and stigmas are free. C, One pistil of the Canterbury Bell: made up of three joined carpels whose stigmas are free. D, One pistil of the Primrose: made up of five carpels completely joined.

This complete separation of the carpels of the pistil one from another occurs in the Buttercup Family (Ranunculaceæ), and in the Rose Family (Rosaceæ).

Joined Carpels.

It is, however, much more usual to find the carpels united. In the Nottingham Catchfly, as in the Pinks generally, the pistil is made up of three carpels. This is evident because there are three distinct stigmas and styles, but the basal parts of the carpels are most intimately united (Fig. 187, B).

In the Canterbury Bell and Harebell the styles also are joined, and only the three stigmas project freely (Fig. 187, C).

In the Primrose there are five carpels, and the junction of these is complete, resulting in one round, knob-like stigma, one slender style, and an ovary which is one hollow chamber (Fig. 187, D).

Thus there is every gradation from a pistil made up of free carpels to one that is made up of carpels so completely joined that it is difficult to tell their number by superficial examination.

Because of these variations the morphology of the pistil presents some little difficulty at first. It is, however, easy to remember that when the sepals, petals, and stamens have all been removed, that part of the flower which remains is the pistil, or gynœcium; this is made up of leaves called carpels; these carpels may be free from one another or may be joined in varying degree.

The floral leaves that form the whorl outside the pistil are the stamens. Together they constitute the *andrœcium* (Greek *aner*, *andros*, a male ; *oikos*, a house).

The Andrœcium. Like the carpels, the stamens may be free from one another, standing up independently in the flower. This is much the commonest arrangement. When they are joined, the union must be either between the filaments or the anthers.

In the Sweet Pea and its relations (Leguminosæ) there are ten stamens. These are united by their filaments in such a way that they form a sheath enclosing the ovary. In some members of the family all the stamens are joined in this way. In others one remains free (Fig. 253). In a small number of the Legume Family, for example, the Prairie Bean, the stamens are quite separate from one another.

In the Compositæ, the Dandelion Family, the five stamens of each flower are united by their anthers, a condition which is known as *syngenesious* (Fig. 194, C).

It is obvious that the stamens of the andrœcium and the carpels of the gynœcium are the essential leaves of a flower. Upon them the persistence of the species depends. They are the definite organs of sexual reproduction, and other parts that may be present are purely accessory.

The Essential Floral Whorls.

The flowers of all grasses and of many trees are made up of these two parts only. For this reason they are inconspicuous, and it is a surprise to many people to learn that such plants bear flowers.

Wind Pollination. Often they are so simple that a flower consists of stamens only, or of carpels only. The male flower of the Birch is made up of two stamens, which fork and look like four. The female flower is merely one carpel. Because of their extreme simplicity they are massed together in long inflorescences, called catkins. As the male catkin sways in the wind its very light pollen is wafted to the female catkins, which are on the same tree. The two long stigmas of each carpel catch some of the pollen. To ensure pollination, not only is a vast amount of pollen produced, but the flowers are mature while the foliage leaves are still too small to hinder the free passage of pollen from the male to the female catkins.

Similar conditions obtain in the Oak. In the Hazel, Elm, and Poplar the leaf-buds do not burst until pollination is completed (Fig. 188). A further variation in the Poplar is, that the male catkins occur on one tree and the female on another.

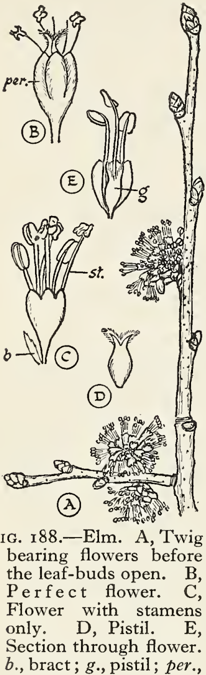


Fig. 188.—Elm. A, Twig bearing flowers before the leaf-buds open. B, Perfect flower. C, Flower with stamens only. D, Pistil. E, Section through flower. *b.*, bract; *g.*, pistil; *per.*, perianth; *st.*, *stamen.*

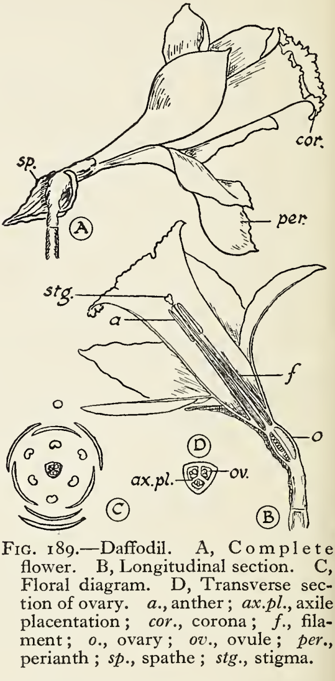


Fig. 189.—Daffodil. A, Complete flower. B, Longitudinal section. C, Floral diagram. D, Transverse section of ovary. *a.*, anther; *ax.pl.*, axile placentation; *cor.*, corona; *f.*, filament; *o.*, ovary; *ov.*, ovule; *per.*, perianth; *sp.*, spathe; *stg.*, stigma.

Insect Pollination.

In contradistinction to wind-pollinated flowers, those that are insect-pollinated have all, or some, of the following characteristics: they contain honey; they are brightly coloured; they are sweetly scented. That is, they are just as definitely conspicuous as wind-pollinated flowers are inconspicuous.

It is the two whorls surrounding the andrœcium and gynœcium that co-operate to give the insect-pollinated flower its most marked characteristics. These two sets of leaves form the *perianth*.

The Perianth.

In most of the insect-pollinated flowers of plants known as *Monocotyledons* there are three very similar perianth leaves in each whorl. These alternate, so that the outer three leaves fill up the gaps which occur between the three inner. A familiar example is the Tiger Lily.

In Monocotyledons.

The long trumpet, or corona, of the Daffodil grows from six perianth leaves that are joined (Fig. 189). In the Tulip the perianth leaves are free and fall off separately when the flower is dying. In the Hyacinth the outer leaves perhaps curve outwards just a little more at the tip than do those of the inner whorl. In the Snowdrop there is a good deal of difference in the two whorls; not only are they differently marked, but the three inner perianth leaves are shorter and thicker than the outer ones, and they are grooved on their inner surfaces, the grooves being nectaries (Fig. 157).

In most *Dicotyledons* the two whorls of the perianth are very distinct. The outer whorl, or *calyx*, is generally green, and its *sepals* may form a cup.

In Dicotyledons.

The colour, the scent, and often the honey also, depend upon the *petals* that make up the *corolla*.

The function of the calyx is largely protective. When the flower is in bud it tightly encloses the three floral whorls within it. When the flower is open it fills in the gaps between the petals, and so prevents insects from forcing an entrance at these areas of least resistance. Such an entry would be prejudicial to the flower, because the visiting insect would get the honey provided without conferring any benefit in return. When it enters according to the set design, pollination is effected.

The Calyx.

The sepals, too, help to hold the rest of the flower together. When a Poppy bud opens the petals withdraw from the sepals, which are sloughed off and fall to the ground. This accounts for the fragility of Poppy flowers; their petals have no permanence.

In some cases, again, the sepals take on the work of petals and attract insects by their colour and their size. The purple leaves of the Clematis, the yellow leaves of the Marsh Marigold, the many-coloured leaves of the Anemone, are all sepals (Figs. 195 and 200). Petals are entirely absent in these three flowers.

The Corolla. The petals of the corolla do not only play a part in pollination because their colour, size, and smell attract insects. Quite frequently their shape is such that they accommodate, in a marked manner, the body, or part of the body, of one particular insect, it may be to the complete exclusion of others.

Frequently, too, the petals are so arranged that an insect, entering the flower, can only reach the honey by following a course that inevitably brings a definite part of its body into contact with the anthers and stigmas.

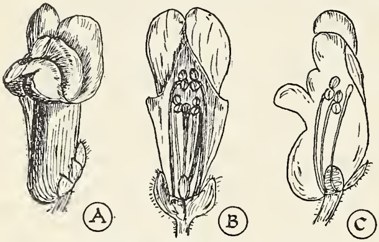


FIG. 190.—The Snapdragon. A, The whole flower, showing the firmly closed lips of the corolla. B, The same with the lower lip removed. C, Longitudinal section of a flower in an early stage: later the stigma occupies the position now held by the anthers.

In many flowers the particular design that is good for securing the best possible advantage from insect visits is also remarkably efficacious in protecting pollen. If pollen gets thoroughly damp it is useless. In one way or another the petals so protect it that it is not wetted even in the sharpest shower.

The Snapdragon. The Snapdragon owes its name to its tightly closed petals. The two lips of the corolla meet so firmly that a bumble-bee is the only insect able to force an entrance (Fig. 190). Honey is secreted by a little disk at the base of the ovary. As the bee, exerting strength, pushes well into the flower, its back rubs on the domed upper lip of the corolla.

Four stamens, two of which have long, and two short, filaments, are inserted on the corolla and follow the curve of the upper lip. Their anthers open in such a way as to let the pollen fall to the centre of the flower. Such anthers are *introrse.*

In this flower, as in so many others, the anthers open to let the pollen escape before the stigma of the flower is ready to receive it. That is, the flower is *protandrous*. In this very simple way self-pollination is prevented.

The bee visiting a Snapdragon with mature stamens, receives a charge of pollen on its back. It may visit one protandrous flower after another, thus increasing its pollen-load. When the stamens have shed their pollen the anthers wither and the slightly two-lobed stigma, which was at first very much in the background, now occupies their place. When the bee enters a flower at this stage, its back comes in contact with the stigma, and it leaves upon it some of the pollen it is bearing. In this way cross-pollination of the Snapdragon is brought about by bumblebees only.

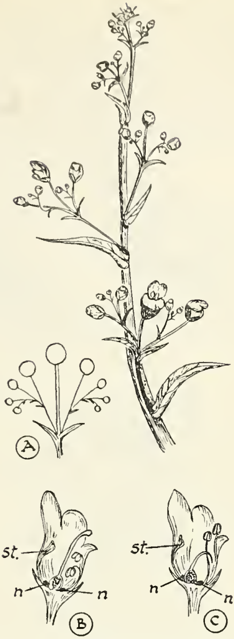


Fig. 191.—Figwort. The upper part of the mixed inflorescence. The main branching is racemose, but a cymose inflorescence develops in the axil of each bract. A, Diagram of one axillary inflorescence, which begins as a dichasium, and then becomes monochasial, with the branches growing from the same side. B, Section of a newly opened flower, with the stigma against the lower lip. C, Section of the same flower, later, when the anthers occupy the position formerly held by the stigma. *n.*, nectary ; *st.*, staminode representing the missing fifth stamen.

The Figwort flower is *protogynous*, that is, the stigma in

The Figwort.

each flower is in a receptive state before the anthers are mature. It is pollinated by wasps, attracted in part by the raw-meat colour of the petals. The shape of the flower is such that it exactly accommodates this insect's head and thorax. In this case it is the ventral part of the head and thorax of the wasp that gets coated with pollen, because the stamens and stigma rest on the lower lip of the corolla (Fig. 191).

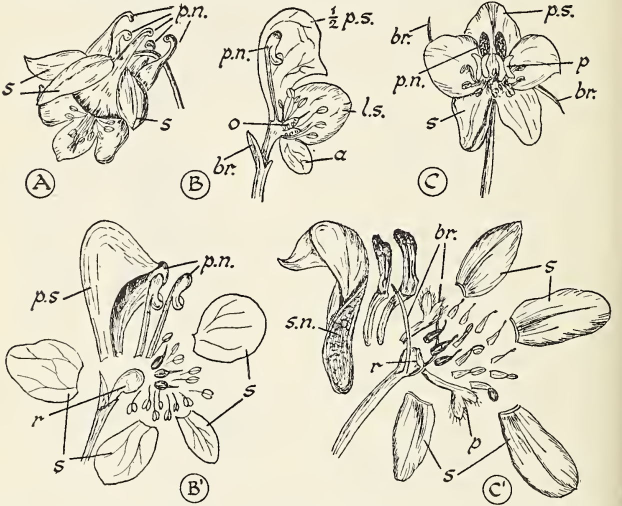


Fig. 192.—A, Columbine. B, Longitudinal section of Monkshood. B^1, Dissection of flower of Monkshood. C, Delphinium (Larkspur) seen from the front. C^1, Dissection of flower of Delphinium. *a.*, anterior sepal; *br.*, bracteole; *l.s.*, lateral sepal; *o.*, ovary, marginal placentation; $\frac{1}{2}$*p.s.*, half posterior sepal; *p.s.*, posterior sepal; *p.*, petal; *p.n.*, petal (nectary); *r.*, receptacle; *s.*, coloured sepals; *s.n.*, posterior sepal in which honey collects. In B^1 and C^1 the three carpels are dark and near the receptacle. In C^1 the outer stamens are barren.

The Columbine.

In the Columbine brightly coloured sepals alternate with very characteristic petals (Fig. 192, A). Each petal is funnel-shaped and drawn out into a long spur which secretes honey at its thickened distal end.

The length of the spur makes the honey inaccessible to any but long-tongued insects. In a newly opened flower the stamens give a firm resting place for an insect, whose ventral surface rubs off much of the pollen. In an older flower, when the anthers are withered, a similar platform is provided by five free carpels, which stand firmly upright, so that when they are in contact with the insect, pollen is left upon the five stigmas.

The Delphinium.

The Delphiniums that figure so largely in the herbaceous perennial border of every garden owe their beauty to the colour and form of the sepals. The two posterior petals are most un-petal-like in form. They are projected downwards as two long spurs which are the nectaries. These fit into a pouch of the posterior sepal, where the honey collects (Fig. 192, C^1).

Again the honey is so placed, not merely that it can only be reached by long-tongued insects, but that these, in their quest, must arch their bodies over the mass of stamens that in a young flower block the passage. In this way pollen collects upon the insect's ventral surface. In an older flower the stamens are shrivelled and out of the way, but the passage is now blocked by the three free carpels that the stamens surrounded. Their stigmas come in contact with that part of the insect's body that is carrying pollen.

Thus pollination in the Columbine and Larkspur is brought about successfully, because the whole design of the flower makes it impossible for an insect to reach the honey without, at the same time, acting as an agent in the transference of pollen. In Monkshood a similar device obtains for securing cross-pollination. The blue perianth leaves of this flower are all sepals. The posterior sepal is in the form of a hood; this encloses two petals curiously modified to form nectaries (Fig. 192, B, B^1).

Devices to Secure Cross-pollination.

The successive maturing of stamens and carpels, characteristic of Columbine and Larkspur, is a common device for ensuring cross-pollination. Generally speaking, seeds are better, that is, they produce better plants, if they have been formed by the interaction of the pollen of one flower and the ovule of another.

Even if the two flowers have been growing on the same stem, as in Foxglove or Delphinium, cross-pollination gives better results than self-pollination.

When the flowers grow on different plants, the result is better still.

Often, too, the strain is markedly improved when the crossed flowers have grown under different conditions, that is, separated in space. Darwin found that he got much better seeds as a result of his experiments when he cross-pollinated flowers growing on opposite banks of the Cam, than when the cross was made between flowers growing on the same bank.

It is not surprising, therefore, to find that protandry, as in Columbine and Delphinium, is not the sole device to secure cross-pollination.

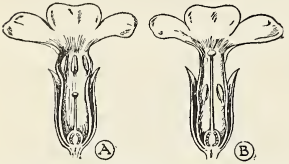


FIG. 193.—Longitudinal sections of Primrose flowers. A, Thrum-eyed. B, Pin-eyed.

In many flowers the stamens reach a lower level than the stigma. This is so in the pin-eyed flower of the Primrose, and is an arrangement that, at least, makes self-pollination difficult (Fig. 193).

When the flowers are unisexual, as in Willow, Poplar, and Hazel, self-pollination is obviously impossible (Fig. 242).

The Primrose.

In the thrum-eyed flowers of the Primrose, not only are the anthers at a higher level than the stigma but, as in the pin-eyed flower, anthers and stigma reach maturity at the same time. Self-pollination would seem to be inevitable in the case of the thrum-eyed flower (Fig. 193, A). As a matter of fact, it is only extremely rarely that it occurs. Time and again it has been demonstrated, in this particular Primrose, that if insect visits are prevented by shielding the flower in some way, it is most unusual for fertilisation to take place.

The explanation of this is found in the large size of the pollen grains of thrum-eyed flowers. They are too big to find anchorage on the stigma below them, for this is only adapted to receive the smaller pollen grains from the pin-eyed flowers.

As might be expected, then, the uplifted stigma of a pin-eyed flower is provided with hairs and irregularities that accommodate the large pollen grains of the thrum-eyed flowers.

Thus all is well arranged, and pollination takes place through the agency of long-tongued insects. The part of the proboscis that touches the anthers, and so collects pollen in one form of flower, is the part that touches the receptive stigma when a flower of the other form is visited (Fig. 193).

The shielding of flowers just suggested is frequently resorted to in pollination experiments.

The Need for Pollination.

In the particular case of the Primrose the flowers can be shielded by putting a bell-jar over a whole plant because all its flowers are of one kind. There is no mixing of pin-eyed and thrum-eyed flowers.

In other cases the shielding is effected by tying up one individual flower of a plant in very fine muslin. Tulips are good to choose for preliminary experiments because their flowers are so large.

The six stamens of a flower must be cut off with care as soon as the flower pushes up from the bulb. A piece of fine butter muslin is then tied lightly, but firmly, over the flower head. Self-pollination cannot take place because the stamens have been removed. Cross-pollination cannot take place because the entrance of insects is effectually barred.

The result is that no seeds are formed and the ovary is of small size as compared with other free Tulips that surround it. This is a simple way of demonstrating the need for pollination as a preliminary to seed production.

It may be argued that the cutting off of the stamens has given the plant a shock which would in any case prevent seed formation. It is well, therefore, to remove the stamens of some unshielded flowers. These are accessible to insect visitors and are found to produce seeds normally.

In some flowers self-pollination is prevented by the very curious condition of self-sterility. The pollen grains of a flower simply do not germinate on the stigma of the flower that produced them. This is true of the Bitter Buttercup.

In a few cases there is actual antipathy between the pollen and stigma of the same flower. The flowers of some Orchids are actually killed when the pollen from their own stamens is put upon their stigmas.

At the other extreme there are flowers in which the whole aim is to secure self-pollination.

Self-pollination.

The petals in the flower of the Garden Pea are so firmly interlocked that no insect forces an entrance. Self-pollination must take place in this case, for pods normally contain the full complement of peas.

In Orchids the pollen occurs in club-shaped masses. In the Bee Orchis these masses fall forwards on to the stigma of the flower when it is in any way disturbed. In this case an insect may bring about self-pollination by alighting on the flower and causing a slight tremor.

In addition to the sweet-smelling flowers of the Violet, the plant bears others which appear later. They are green and inconspicuous and never open. They have the appearance of buds and must be looked for quite low down, underneath the foliage leaves. In these flowers, which are called *cleistogamous* (Greek *kleistos*, closed ; *gamos*, married), not only does self-pollination take place, but the seeds which they produce are invariably of good quality.

Here, then, are the two extremes. On the one hand, impossibility of self-pollination. On the other, impossibility of cross-pollination. Between the two are many cases of flowers that have, as it were, two strings to their bow. If cross-pollination does not take place, then they resort to self-pollination.

If the Scarlet Pimpernel has not been cross-pollinated the flower closes up and remains closed for two or three days. When it re-opens pollination has taken place.

If in spite of colour, scent, and honey the Wallflower has not been visited by insects, the four long stamens grow a little and bend, so that their anthers arch over the stigmas. The pollen then falls on to the stigmas and the ovules are fertilised.

In the Dandelion, Daisy, Sunflower, and members of the Compositæ generally, pollination never fails, and probably this accounts for the great success of the Family. It includes more than 10 per cent. of the flowering plants of the world and is represented in all parts of the globe.

In some members of this Family the flat inflorescence consists of strap-shaped flowers only, as in the Dandelion. In others there are only tubular flowers, as in Common Groundsel and Canada Thistle. In others ligulate, or strap-shaped, flowers are on the outside of the inflorescence and the tubular flowers are centrally placed, forming a compact disk.

Pollination in Compositæ.

In the tubular, or disk, flowers of the Giant Sunflower the course of pollination may be readily traced (Fig. 194).

In these flowers two small scales represent the calyx.

The corolla is made up of five superior petals, joined so that they form a tube.

On the corolla grow the five stamens, whose filaments are slightly curved because the anthers unite. In uniting they form a narrow chimney, or hollow cylinder.

The pistil is made up of two joined carpels, the ovary being inferior.

The interest centres in the behaviour of the style and forked stigma.

The two arms of the stigma are rather long and are only stigmatic, that is, only able to hold the pollen grains, on one surface. In a young flower the two stigmatic surfaces face one another and practically meet, so that the bifid stigma, at this stage, scarcely appears divided. The other surfaces of the two stigmatic arms are covered with fine hairs.

The syngenesious anthers open introrsely, so that the pollen lies loose in the hollow cylinder. At this stage the style elongates and the stigma is swept up this cylinder, much as a chimney-sweep's brush sweeps up a chimney. In the hairs of the stigma the pollen is entangled as soot is held in the chimney-sweep's brush (Fig. 194, C).

On examination, young unopened flowers are probably seen in the centre of the Sunflower disk. Surrounding these are slightly older ones in which the anthers are seen above the petals. In still older ones the hairy stigma has pushed through the joined anthers, raising their pollen above the general level. In flowers still nearer the circumference the stigmatic arms have parted, so that the actual stigmatic surfaces face upwards (Fig. 194, D).

Now pollination may take place. Any insect, creeping over the flower head, may carry the pollen that is held on the erect stigmas to those that are outstretched in the older flowers. A bee, or butterfly flying from quite another Sunflower, may perform the same office.

There seems to be boundless opportunity for cross-pollination. In some cases, however, it is missed. Then the outstretched stigmatic arms curl towards the style and continue curling until their sticky stigmatic surfaces are in actual contact with the hairs of their under surfaces (Fig. 194, E). The result of the contact is the transference of many of the pollen grains from the hairy under surface to the upper stigmatic surface. Thus self-pollination takes place and fruits are then formed from the flowers even when insect visits have failed.

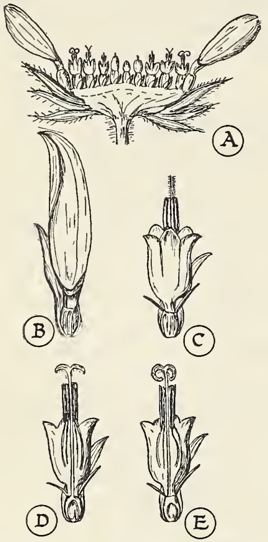


Fig. 194.—A, Inflorescence of the Sunflower: a capitulum. B, Barren ray flower. C, D, E, Disk (tubular) flowers of different ages.

The Inflorescence.

The flowers of all members of the Compositæ are so extremely small that they would stand but little chance of cross-pollination if they were not massed together in a dense cluster, or *inflorescence*.

Aggregations of flowers to form inflorescences are extremely common. It is only in comparatively few cases that one solitary flower grows on the flowering axis. This is, however, the arrangement in the Daffodil, and the Anemone. In such cases the inflorescence is said to be *solitary*, and, as the flower is at the end of the axis, it is also called *terminal* (Fig. 195).

A *solitary* inflorescence that is, at the same time, *axillary* is found in the Scarlet Pimpernel (Fig. 196). Here each flower stalk, bearing one flower only, grows in the axil of a leaf. The leaf then receives the special name of *bract*. Any leaf in the axil of which a flower grows is a bract.

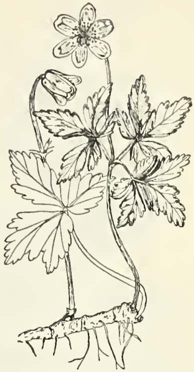


FIG. 195.—Wood Anemone, a solitary, terminal inflorescence. The three bracts are shaded, the foliage leaf is merely outlined. The partially opened flower on the branch of the rhizome shows the sleep position of the flower.

Little leaves are frequently borne on the stalks of individual flowers. These are *bracteoles*, or *prophylls*. Two small prophylls occur on either side of the flower stalk in the Violet (Fig. 250). In the Daffodil two prophylls have united to form the green, protecting wrapping of the flower bud (Fig. 189); when the flower has opened, this remains on the stalk as a brown and shrivelled structure. A protective involucre of three leaves surrounds the flower of the Anemone and Love-in-a-Mist (Fig. 195).

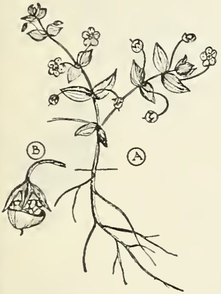


FIG. 196.—A, Solitary axillary inflorescence of Scarlet Pimpernel (Poor Man's Weatherglass). B, One Capsule (a pyxidium) opening by the separation of a lid.

Specialised bracts are found in many flowers whose fruit is a nut.

The Hazel nut is enclosed in a lobed *cupule*, or husk, which is formed from the persistent bracts of the female flower (Fig. 197).

The cup of the acorn is made up of numerous leaves which have become woody after fertilisation has taken place (Fig. 198). The leafy nature of the cup is plainly seen in the fruits of the Turkey Oak.

Similarly the rough husk of Beech nuts and the very prickly cupule of the Spanish Chestnut are formed from modified leaves (Fig. 165).

In vegetative branches a distinction has already been made between monopodial and sympodial growth. A similar difference is met with in the growth of the flowering axis.

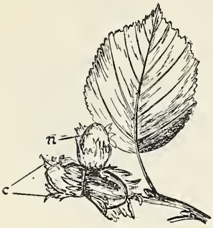


Fig. 197.—Hazel fruits. *c.*, cupule of bracts; *n.*, nut.

In the Foxglove the main flowering axis goes on growing almost indefinitely at the tip, new flowers being produced laterally. Counting the fruits already formed on the lower part of the axis, and the flowers, and the buds, it is not unusual to reach as high a number as 350, and this with the possibility of still more buds developing round the growing point.

Plainly this is *monopodial* growth.

In Stitchwort (Stellaria) and Gypsophyllum the first-formed, that is the oldest, flower is produced at the tip of the flowering axis, and therefore effectually puts an end to any further growth in length. Lateral shoots grow to a higher level, but here again the growth is strictly limited, or definite, because each ends in a flower. The same thing occurs in the lateral branches to which they give rise.

Here, then, the growth is *sympodial.*

An inflorescence that exhibits such sympodial growth is *cymose.*

A *racemose* inflorescence is one in which monopodial growth obtains.

Differences in cymose inflorescences depend upon the position of the lateral branches.

Forms of Cymose Inflorescence.

(1) It may be, as in the Stitchwort, that the branches are in pairs, each flower arising in the axil of a bract on either side of the terminal flower (Fig. 199). These secondary branches also bear paired branches; so do the tertiary branches in their turn; and so on. Sometimes the branches grow equally. More com-

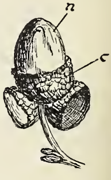


Fig. 198.—Fruit of Oak. *c.*, cupule of bracts; *n.*, nut.

monly one member a of pair grows less strongly, or is even completely suppressed. For this reason diagrammatic exactitude is seldom attained.

Such a cymose inflorescence is a *dichasium*.

(2) Another possibility is that the branches may come off singly, one being developed to the right, another to the left. This produces a zigzagging effect. The Iris, Marsh Marigold, and Forget-me-not have this type of *monochasial* cyme, which is called *scorpioid* (Fig. 200).

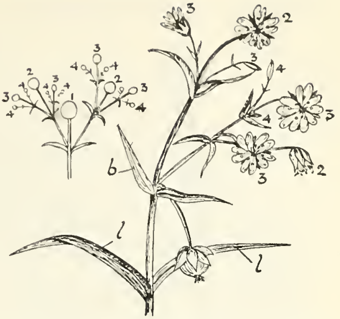


Fig. 199.—The inflorescence of Stitchwort (dichasial cyme). The flowers are numbered in the order of their unfolding. In the oldest, withered styles are seen at the apex of the fruit. *b.*, bract ; *l.*, foliage leaf.

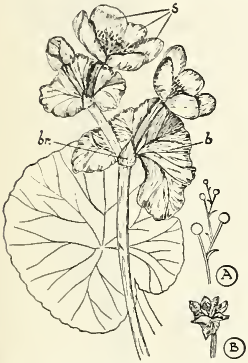


Fig. 200.—Kingcup (Marsh Marigold). A, Diagram of this type of inflorescence (a scorpioid cyme). B, Head of fruits from one flower (collection of follicles). *b.*, bract ; *br.*, bracteole or prophyll ; *s.*, sepals, bright yellow. The foliage leaf is drawn in outline.

The first basal part of the inflorescence axis and the branches become equally thickened. The result is that the zigzagging is not always obvious, for the axes of different orders (1, 2, 3, 4, 5) tend to straighten and look like one.

(3) In some Monocotyledons the branches of the cymose inflorescence all arise on the same side. This form, which is known as *helicoid*, occurs in Rushes and the Star of Bethlehem.

An inflorescence that is racemose may have a long or a short main axis.

Forms of Racemose Inflorescence.

(1) The *raceme* itself often has a very long axis. The lateral branches are flowers whose flower stalks, or *pedicels*, are nearly equal in length. Each flower develops in the axil of a bract, as in the Foxglove, Antirrhinum, and Toadflax (Fig. 201).

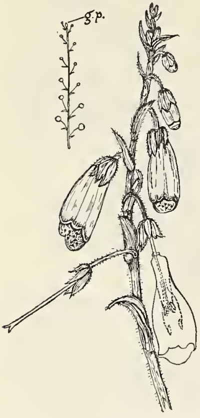


FIG. 201.—The inflorescence of the Foxglove (raceme). *g.p.*, the growing point. The outlined flower shows self-pollination taking place when cross-pollination has failed. As the corolla slips off, the anthers leave pollen on the stigmas which they rub against in passing.

(2) In a *corymb* the flowers grow upon the long axis at some distance one from another, just as they do in the raceme. But as the pedicels of the lower flowers are long, all the flowers reach the same level round the growing point (Fig. 202). Candytuft is a typical corymb. Many other members of Cruciferæ are corymbs in the upper part of the inflorescence, but bractless racemes in the lower, because the pedicels do not elongate.

(3) The *spike* is a much less common racemose inflorescence. The long axis in this case bears *sessile* flowers, that is, flowers which have no pedicels but grow directly on the *peduncle*, or main stem. It is found in Plantains (Fig. 203).

(4) In the *catkin* the raceme is often pendulous and the flowers are always unisexual (Fig 244).

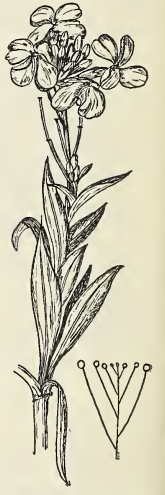


FIG. 202. — Inflorescence of the Wallflower. A Corymb.

(5) The *spadix* is still less common. It differs from the spike in that its axis is thick and fleshy and the whole is surrounded by one very large bract or *spathe*. This is the

inflorescence of the Arum Lily (commonly grown in greenhouses) and of the British Wild Arum—the Cuckoo Pint or Lords and Ladies (Fig. 204).

Pollination in the Arum is most interesting. The very simple female flowers are at the bottom of the spadix. A short distance above these are the male flowers. Above these, again, are sterile flowers with downwardly directed, hair-like prolongations. These hairs occur just where there is the constriction in the spathe, so that the whole design is much like that of a lobster pot.

Little insects, such as small flies and midges, probably covered with pollen from another Arum, find an easy entrance into the spathe, down and between the sloping hairs. They are fussy because they find no food ; their escape is prevented by the sterile flowers. In their purposeless wanderings they leave much of the pollen they were carrying upon the receptive stigmas of the basal female flowers. After this the stigmas wither and exude drops of honey by way of compensating the insects for their imprisonment. The sterile flowers wither also, and a way of escape is clear, but it must be taken over the staminate flowers, which have now shed their pollen. Thus the insects become loaded with pollen once again, and not profiting by experience, they enter another spathe and pollinate another set of female flowers.

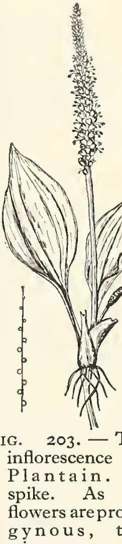


Fig. 203. — The inflorescence of Plantain. A spike. As the flowers are protogynous, the stigmas are projecting from the unopened flowers nearest the apex.

6. An *umbel* has a main axis from which spring a number of pedicels of equal length, so that the whole inflorescence looks a little like an umbrella blown inside out. A *simple umbel* is less common than a *compound* one (Fig. 205). In the latter the branches that arise on the main axis give rise to other branches instead of bearing flowers directly.

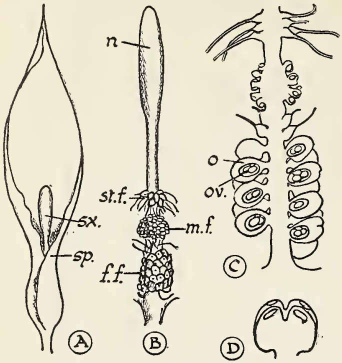


Fig. 204.—Arum. A, Inflorescence enclosed in spathe. B, Inflorescence with spathe removed. C, Longitudinal section through fertile portion of spadix. D, Anther. *f.f.*, female flower; *m.f.*, male flower; *n.*, naked portion of spadix; *o.*, ovary; *ov.*, ovule; *sp.*, spathe; *st.f.*, sterile flower; *sx.*, spadix.

Umbels, both simple and compound, are the characteristic inflorescence of Umbelliferæ, the family which includes the Carrot, Parsnip, Parsley, and Water Hemlock or Cowbane. The latter is poisonous to cattle and various other animals.

The inflorescence of the Primrose is a simple umbel. In this case the short main axis is a flat rhizome. A similar rhizome, seen above the surface of the soil in the flower-pot, occurs in Cyclamen, which also belongs to the Primulaceæ. In Cowslip and Oxlip it is obvious that the inflorescence is an umbel (Fig. 206).

7. In the *capitulum* a flattened axis expands to form a conical or disk-shaped receptacle. On this, numerous sessile flowers grow. The whole head is surrounded by a number of bracts which form an involucre (Fig. 194).

Every member of the Compositæ has this particular type of inflorescence.

The Mixed Inflorescence. In many plants the inflorescence is neither definitely one thing nor

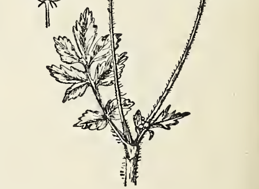


Fig. 205.—The compound umbel of the Wild Parsnip. In this particular species bracts are seldom found.

the other, being a mixture of cyme and raceme.

In the Deadnettle the growth of the main axis is indefinite. The growing point keeps its freedom and produces new lateral growths for some time, while the axis is elongating. The white two-lipped flowers that grow in the axils of the paired bracts are, however, disposed in paired cymes (Fig. 207). The oldest flower of each half of the square stem has a younger one on each side of it and each of these is flanked by a small scorpioid cyme.

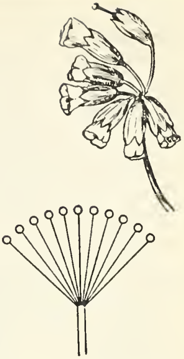


FIG. 206.—Simple umbel of the Cowslip.

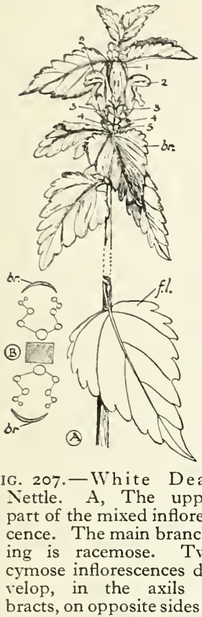


FIG. 207.—White Dead Nettle. A, The upper part of the mixed inflorescence. The main branching is racemose. Two cymose inflorescences develop, in the axils of bracts, on opposite sides of the square stem; meeting, they form an apparent whorl, or *verticillaster*. The flowers in one half-verticillaster are numbered according to age. B, Diagram of a verticillaster; each half begins as a dichasial cyme and then becomes monochasial, with the branches growing alternately, right and left. *br.*, bract; *f.l.*, foliage leaf.

The meeting of the paired cymes makes an apparent whorl of flowers, to which the name of *verticillaster* is given.

Sleep Movements.

Just as there is sleep movement in foliage leaves, so is there the corresponding tropism in flowers. When Dandelions are picked they hide their beauty by closing up. They perform a sleep movement at the wrong time of day.

In the Dandelion, as in all Composites, the sleep movement is not the response of one single flower, but of a whole inflorescence. The mechanism of the closing up of the inflorescence at night differs in different plants.

In all the Composites the pollen is pushed up by the growth of the style and therefore it is in a very exposed position. The sleep movement is designed to keep the pollen dry when rain or dew is falling.

In the Dandelion and Goat Chicory (Prairie Dandelion) and all the plants with ligulate flowers, each corolla strap bends inwards, so as to protect either its own pollen or that of its neighbours.

When tubular flowers occupy the centre of the inflorescence they are protected from the wet by the ligulate flowers and bracts, which change from a horizontal to a vertical position, then arch over towards the centre and make an excellent tent-like shield.

The devices adopted by flowers for keeping pollen dry are very varied. In addition to barring the entrance to all insects but the bee, the firmly closed corolla of the Snapdragon also keeps out rain (Fig. 190). In this flower there is no possibility of the pollen getting wet. It is obvious that this could not be a universal arrangement. The very perfection of pollen protection would make pollen transference impossible. The principle of the tightly closed flower is not economically sound.

The flat, open arrangement of petals in the Scarlet Pimpernel is just at the other extreme. Five stamens stand rigidly erect at right angles to five horizontally placed petals. And yet so perfect is the protection here that the plant has gained the popular name of Poor Man's Weatherglass.

When the atmosphere is becoming charged with moisture an inequality of basal growth, on the outer surface of the petals, produces extra cells at this point. By their intrusion the individual petal is pushed upwards and forwards. By the time the five petals have met and closed in the central part of the flower, the flower stalk itself has bent and brought the whole flower into an inverted position.

The subsequent opening of the flower in a dry atmosphere depends upon additional basal growth on the inner surface of each petal.

Such a temporary inversion as occurs in the Scarlet Pimpernel is seen in many flowers of a similar open form. Poppies, Anemones, Rock Rose, and Herb Robert, all bend downwards before rain comes on or before dew falls at night (Fig. 195).

In some flowers the inverted position of the flower stalk is normal.

When a Hyacinth inflorescence pushes upwards from the bulb all its buds are erect. When the flowers are fully expanded the short pedicels have turned through a considerable angle and face downwards. Rain, falling on the perianth, does not reach the stamens. If, when the flowering time was over, the Hyacinth fruits were in this position, the seeds would all fall down together in one spot. To ensure better distribution the pedicels change position once more, so that the fruits become erect; when they open and the wind blows, the seeds are sufficiently widely scattered (Fig. 208).

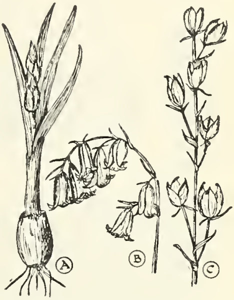


Fig. 208.—The flowering axis of the Wild Hyacinth. A, Young inflorescence with flower-buds erect; B, expanded inflorescence with drooping flowers; C, Axis bearing erect fruits.

The infinite variety that occurs in flower structure is further exemplified in the relative positions that the floral leaves occupy on the *thalamus*, or *receptacle*.

Relative Position of Floral Leaves.

In the Buttercup the numerous free carpels of the pistil occupy the apex of the receptacle. The numerous free stamens are at a slightly lower level. The five free petals are inserted below the stamens. The five free alternating sepals are below these again (Fig. 210). The floral axis is extremely short, and the nodes are very close together. The flower is, in fact, a dwarf shoot bearing variously modified leaves.

A dissection of a White Water Lily is a beautiful demonstration of floral leaf-modification. When sepals, petals, and stamens are arranged in a long line the transition from one form to another is most striking (Fig. 209). The firm green sepals, apart from size, bear some resemblance to the foliage leaves. They are followed by somewhat less sturdy leaves which are greenish-white. Succeeding these are leaves which are whitish-green. Then come large, spreading, white petals. These are followed by narrower ones, on some of which there is a lateral pollen-sac near the tip. Others, still narrower, may bear two such sacs. There is still further narrowing of the leaf, and gradually the petals pass into the numerous stamens with slender filaments and elongated anthers.

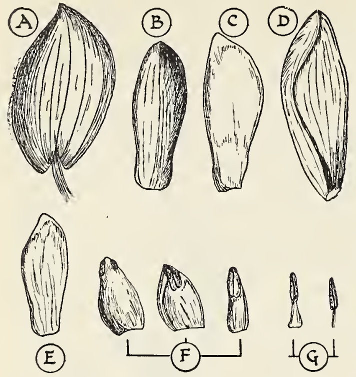


Fig. 209.—White Water Lily. A, Foliage leaf. B, Sepal. C, Greenish-white petal. D, Large white petal. E, Smaller white petal. F, Petals decreasing in size and bearing pollen sacs, thus showing a gradual transition to G, stamens proper.

The position of the floral leaves is always referred to that of the pistil. Thus in the Buttercup the pistil is said to be *superior*, because it occupies the apex of the receptacle. The stamens, petals, and sepals, being at a lower level than the pistil, or gynœcium, are *inferior* or *hypogynous* (Greek *hypo*, below) (Fig. 210).

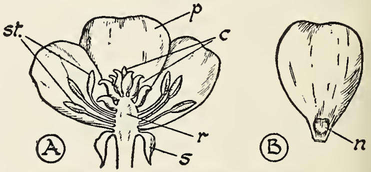


Fig. 210.—A, Longitudinal section of Buttercup (hypogynous). B, Petal with nectary. *c.*, pistil made up of free carpels; *n.*, honey gland; *p.*, petal; *r.*, receptacle; *s.*, sepal; *st.*, stamens.

In some flowers the actual apex of the receptacle stops growing, while growth continues at the region surrounding it in such a way that the whole receptacle becomes a disk. The pistil occupies the centre of the disk and the sepals are on its outer edge. All the floral leaves are growing at the same level. No one part is superior or inferior to another.

Again taking the pistil as the point of comparison, the stamens, petals, and sepals are said to be *perigynous* (Greek *peri*, around).

Such an arrangement obtains in the Sweet Pea and other members of the Leguminosæ (Fig. 253).

In the Rose Family the perigynous arrangement in many of the flowers is extreme.

Perigyny in Rosaceæ.

Spiræa affords the simplest example (Fig. 211, A). Here the circumference has continued its growth in such a way that the actual apex of the axis lies in a depression and the receptacle is in the form of a rather deep saucer.

In Geum (Avens) localised growth at the apex of the receptacle produces a tapering projection on which the numerous free carpels grow (Fig. 211, B). The rest of the perigynous floral leaves are actually at a lower level, because they are inserted on the very slightly concave, disk-like expansion.

This arrangement is also found in the Strawberry, but the projection in this case is rounded, not pointed (Fig. 211, C). After fertilisation the projection grows greatly. It becomes red and succulent and sweet and is much more obvious than the fruits (Fig. 211, C^1). Thus in the Strawberry the part that is so delicious to eat is the receptacle—the actual floral axis. The fruits, formed from the numerous free carpels, are the small hard bodies, dotted all over its surface.

In the Blackberry, Raspberry, and Loganberry the same form of receptacle occurs, but, after fertilisation, it is the individual fruits that become juicy and sweet and increase in size (Figs. 211, D, and 213, B). The receptacle, with the calyx still persisting, is the part pulled out when the fruits are being prepared for eating.

The receptacle in the Plum, Cherry, and Almond resembles that of Spiræa (Fig. 211, E). The margin, however, grows still more, so that the actual apex lies in a much deeper depression.

Unlike most members of the Rosaceæ the pistil is made up of one carpel only.

After fertilisation the urn-shaped part of the receptacle drops off and the fruit is formed entirely from the single ovary. The stimulus of fertilisation induces marked changes in its wall, so that the fruit coat or *pericarp* develops excessively and is differentiated into three layers (Fig. 213, B).

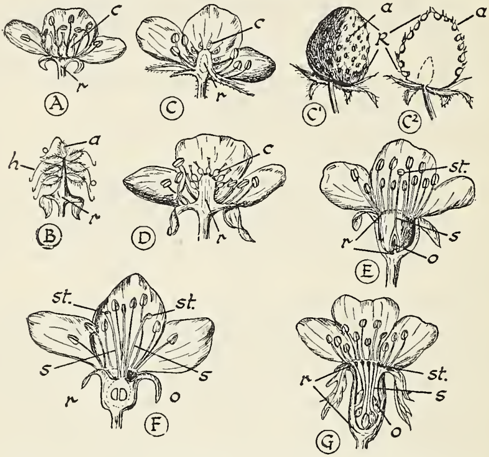


FIG. 211.—Various flowers and fruits of Rosaceæ. A, Longitudinal section of flower of Spiræa. B, Fruits (achenes) of Geum on tapering receptacle. C, Longitudinal section of Strawberry flower. C^1, Strawberry " fruit." C^2, Longitudinal section of Strawberry " fruit." D, Longitudinal section of Blackberry flower; E, Longitudinal section of Cherry flower. F, Longitudinal section of Apple flower. G, Longitudinal section of Rose. *a.*, achene; *c.*, carpel; *h.*, hooked style; *r.*, receptacle; *s.*, style; *st.*, stigma; *o.*, ovary.

The outermost of these is thin, but resistant. Wax deposited in the cutin of its epidermal cells produces the beautiful bloom of the Plum. This layer of the fruit coat is called the *epicarp*. The next layer is sweet and juicy and is the *mesocarp*. The innermost layer is hard and shell-like and is called the *endocarp*. Within the endocarp lies the kernel or seed.

Such a fruit as this, with a three-layered pericarp, is called a *drupe*.

In the Rose the receptacle is similar to that of the Plum, but as it narrows at the top it is still more urn-shaped (Fig. 211, G). Furthermore it is persistent. After fertilisation it increases in size, turns red, and is the familiar hip of roadsides and poplar groves.

When the stamens and petals have fallen off, the numerous stigmas are still seen projecting through the narrow opening of the urn. When a vertical section is cut, the styles, too, are plainly seen, passing upwards from the enclosed fruits.

In the Apple the condition found in the Rose goes one degree further.

The narrow opening of the urn is obliterated, for the receptacle completely encloses the ovaries of the carpels, which are five in number and slightly joined. The five styles and stigmas project upwards in the centre of the flower, surrounded by stamens, petals, and sepals (Fig. 211, F).

It would now be absurd to speak of *peri*gyny, for the ovary is very definitely below all the rest of the flower. The extreme development of the receptacle has, in fact, carried up the three outer whorls of the flower, so that the ovary now occupies an inferior position, while all the rest of the flower is superior, or *epigynous* (Greek *epi*, upon).

It is clear that the part we eat in the Apple is the swollen receptacle. The actual fruit is the five-chambered core, formed from the basal parts of the five carpels (Fig. 218).

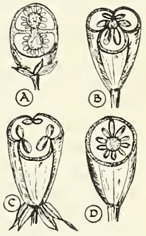


FIG. 212.—Diagrams of types of placentation. A, "Dumb-bell" placentation of Scrophulariaceæ. B, Axile. C, Parietal. D, Free-central.

Further fundamental differences in floral structure depend upon the arrangement of the ovules within the ovary. This arrangement is known as their *placentation* (Fig. 212). To understand this it must be remembered that a carpel is a modified leaf and that it bears marginal ovules, more particularly on the broad basal part of the leaf.

Placentation.

When the leaf folds inwards so that the margins meet, the ovules are in a row on the line of junction. This arrangement is shown excellently in the free carpels of Columbine, Delphinium, and Marsh Marigold. In this case the placentation is *marginal* (Fig. 192).

When two or more carpels similar to this join, so that all the margins meet, forming a *syncarpous* ovary, the ovules lie very near the centre, in the angle or axil formed by the infolding of each leaf. In this case the placentation is *axile* and is well seen in the large ovary of the Tulip.

It may happen, however, that the margins of the leaves are only very slightly infolded. Then, when two or more carpels join, the fused margins form ridges on which the ovules grow. This is the *parietal* placentation of the Violet. In the Poppy the margins project towards the centre, as may be seen in a transverse section of its ovary.

Lastly, the ovules may grow on a short column of tissue in the centre of the ovary, absolutely free from its walls. This is the *free-central placentation* of the Pinks, the Primrose, and the Scarlet Pimpernel.

PRACTICAL WORK

The salient features described in the text may be illustrated by the following Canadian plants :

Marsh Marigold (Kingcup) *or* Anemone.
Buttercup (Crowfoot)—several species available.
Larkspur (Delphinium).
Tiger Lily (*Lilium montanum*).
Rose (several native species and varieties in Western Canada).
Cinquefoil (Potentilla).
Avens (Geum).
Choke Cherry *or* Pin Cherry.
Stinkweed *or* some other species of the Mustard Family.
Prairie Bean (Thermopsis).
Vetch (Vicia) *or* Vetchling (Lathyrus) *or* Caragana.
Stitchwort (Stellaria).
Mealy Primrose (*Primula farinosa*) *or* Shooting Star (Dodecatheon).
Beard-tongue (Penstemon) *or* Snapdragon.
Hemp Nettle (Galeopsis) *or* Wild Mint (Mentha) *or* Woundwort (Stachys).
Sunflower *or* Gum-plant *or* Wild Aster.
Common Dandelion *or* Prairie Dandelion (Goat Chicory) *or* Hawkweed.
Canada Thistle *or* Everlasting (Antennaria).
Poplar *or* Willow.

CHAPTER XXV

FRUITS AND THE DISPERSAL OF FRUIT AND SEED

The essential whorls of a flower are the andrœcium and the gynœcium. Without these a flowering plant would be faced with the alternative of extinction or immortality.

When corolla and calyx are present they play a subsidiary, but none the less very important, part in the work of pollination.

Fertilisation follows pollination, and this act gives such a stimulus to development that not only are ovule and ovary influenced, forming seed and fruit respectively, but neighbouring parts are also affected. The change in the receptacle of Strawberry and Apple, dependent upon fertilisation, is most pronounced. A fruit is not only the structure formed from the ovary after fertilisation. It is the whole result of a stimulus that influences ovule and ovary and, in many cases, the parts that surround the ovary as well.

Of fruits there is an infinite variety. They may be formed from one carpel or from many. They may contain one or a number of seeds. They may, or may not, open or *dehisce* to allow the seeds to escape. The fruit-wall or *pericarp* may be dry or juicy.

Classification of Fruits.

A good classification of fruits is not easy to frame. A preliminary three-fold division into Simple, Aggregate, and Composite makes a fairly satisfactory starting-point.

Simple Fruits.

In some flowers there is only one carpel. This is true of the Leguminosæ. Obviously, then, only one fruit can result from such a flower.

It is equally obvious that only one fruit will result when a flower has two or more carpels if these are joined together.

In both cases the fruit is *simple* because it is produced from a single flower.

Aggregate Fruits.

As there are a number of free carpels in the pistil of the Buttercup there must, of necessity, be a number of free fruits formed from one flower. Such a head of fruits is then spoken of as *aggregate.*

Composite Fruits.

Composite fruits are not common. The Pine-apple, Fig, and Mulberry are examples of this class. In each case much more than the ovary, more even than the ovary and receptacle, has taken part in the formation of the fruit.

The composite fruit is actually formed from a whole inflorescence. Each little area on the outside of a Pine-apple represents one flower. The whole axis of the inflorescence, and all the parts of the flowers it bears, become sweet and juicy and fuse together in the formation of this unusual type of fruit.

In the Mulberry each separate part of the fruit is not a single drupel, as in the Blackberry, but is made up of a central drupe, surrounded by four juicy perianth leaves (Fig. 213).

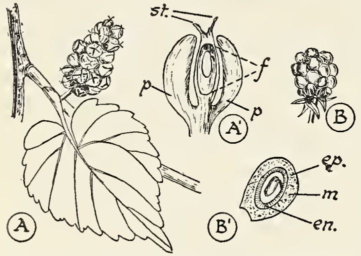


FIG. 213.—A, Mulberry twig, bearing one composite fruit. A^1, Longitudinal section of one area. *f.*, true fruit; *p.p.*, two of the perianth leaves; *st.*, withered stigmas. B, Blackberry fruit (collection of drupels). B^1, Longitudinal section of one drupel. Pericarp: *ep.*, epicarp; *m*, mesocarp; *en.*, endocarp.

Among the simple fruits some are described as *dry* because the pericarp of the mature fruit contains no juice. A nut is a typical dry fruit.

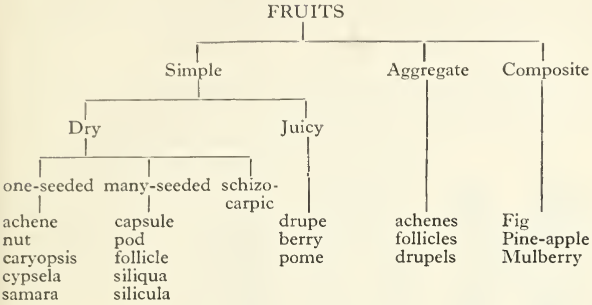
Others are *juicy*, either because the pericarp is juicy, as it is in a Plum; or because the seeds are embedded in a pulpy mass, as in an Orange; or because the receptacle has taken part in the formation of the fruit and has become juicy, as in the Pear.

Then again dry fruits may contain one seed or many. They may be formed from a varying number of carpels and dehisce in different ways.

Schizocarps.

Some dry fruits are formed from syncarpous ovaries, but, although the carpels were joined in the flower, the mature fruit divides into a number of parts, generally corresponding to the number of carpels from which it was formed. Such fruits are called *schizocarps*.

All these points are taken into consideration in framing the classification of fruits which is shown in tabular form below:



One-seeded Fruits.

One-seeded fruits are all indehiscent because there is no need for the fruit coat to open and let the seed escape. When germination takes place the pressure of the escaping root causes a rupture of both testa and pericarp.

The differences between one-seeded fruits are largely differences in the nature of the pericarp.

An *achene* is a dry, one-seeded fruit in which the pericarp is tough or leathery.

In the Lady's Mantle, one of the Rosaceæ, the fruit is an achene. In other cases achenes occur in collections, being formed from an apocarpous (free carpels) pistil.

Collections of achenes are found in the Buttercup, Strawberry, Rose, and many members of Ranunculaceæ and Rosaceæ (Figs. 130 and 211).

A *nut* is a dry, one-seeded fruit in which the pericarp is hard and shell-like. The Hazel and Filbert are familiar examples (Fig. 197).

Many " nuts " popularly so-called are not nuts at all. The Brazil nut and Horse Chestnut are seeds. The Walnut, Almond, and Coco-nut are drupes.

The *caryopsis* is the fruit of all cereals. It is dry and one-seeded. Its distinctive characteristic is the very close adhesion of the fruit coat (pericarp) with the seed coat (testa) (Fig. 238).

The *cypsela* is the fruit of all members of the Compositæ (Fig. 221). It is dry and one-seeded, and its pericarp is frequently tough. It is, however, formed from an inferior ovary, whereas the typical achene results from an ovary that is superior. The striped cypsela of the Sunflower is always found in packets of parrot food.

In the *samara* the pericarp has undergone such a drastic change that it forms a wing (Fig. 219). The samara is a dry, one-seeded fruit in which the pericarp is flattened and expanded to form a wing.

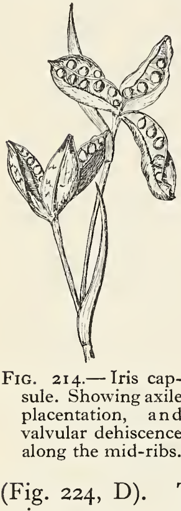


FIG. 214.— Iris capsule. Showing axile placentation, and valvular dehiscence along the mid-ribs.

Many-seeded Fruits.

Many-seeded fruits all agree in being dehiscent because there must be separation of the seeds. The method of opening in the ripe fruit varies, but in every case the seeds escape completely.

A *capsule* is a dry, many-seeded fruit formed from more than one carpel. It dehisces in various ways.

A common form of dehiscence is by means of *valves* (Fig. 214). Longitudinal slits run the length of the capsule and correspond in number to the number of carpels that formed the fruit. The capsules of Willow and Poplar open by two valves; the Iris by three; the Willow-herb by four.

Many capsules open at the apex by *teeth* (Fig. 224, D). The number of teeth is either the same, or twice as many, as the number of carpels. The Primrose capsule opens by five teeth; the Campion by ten. Each of these flowers has a syncarpous ovary formed from five carpels.

In the Poppy a number of *pores* are caused by a breaking away and bending back of tissue in the ripe fruit (Fig. 224, A). They occur just under the flat crown formed by the old stigmas. The number of pores, as well as the number of stigma rays, corresponds to the number of carpels in the flower. Large pores are found in the fruits of Snapdragon and Canterbury Bell (Fig. 224, B).

A very fascinating mode of dehiscence is seen in the fruit of the Scarlet Pimpernel (Fig. 196). The whole top of the capsule comes off most neatly as a *little lid*. As the old style still projects from the top of the fruit, the separating lid looks a little like an elfin cap, and this particular capsule is called a *pyxidium*.

In the basal half of the capsule the seeds are seen attached to a central column because the placentation is free-central.

A similar pyxidium is found in the Plantain, whose rosettes of foliage leaves cover the bare patches of many a waste bit of ground.

The *pod*, or *legume*, is the typical fruit of Leguminosæ (Fig. 228). It is dry, many-seeded, and formed from one carpel. It opens to let the seeds escape by splitting down both sides; that is, along the dorsal and ventral sutures; in other words, along the line that corresponds to the midrib of the leaf and that which corresponds to its united margins.

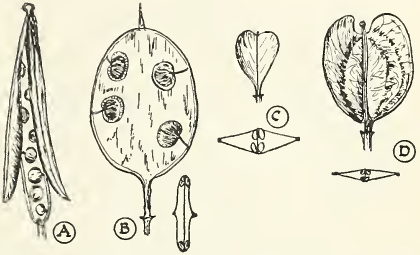


FIG. 215.—Various forms of fruits in Cruciferæ. Cross-sections of these are shown diagrammatically. A, Wallflower, dehiscing. B, Honesty, with half the fruit-coat removed to show the attachment of seeds to the replum. C. Shepherd's Purse. D, Penny-cress.

A *follicle* is also a dry, many-seeded fruit formed from one carpel (Fig. 200). Unlike the pod, it splits down one side only, and that is the ventral. Follicles are seldom found singly because they occur in flowers with apocarpous pistils, as in the Columbine, Monkshood, and Marsh Marigold.

A *siliqua* is long and narrow, and a *silicula* is short and broad (Fig. 215). These are the characteristic fruits of Cruciferæ. They are formed from two carpels. The fruit appears two-chambered, but this condition has been brought about by the growth of a false septum between the two carpels.

When the carpels lie flat so that they are almost in contact, the septum lies in the same plane as the carpels. This condition is found in Honesty (Fig. 215, B).

In Treacle Mustard (Worm-seed Mustard) the carpellary leaf is partly folded along the midrib, so that the fruit is approximately square in section.

More acute bending along the midrib produces the condition found in Shepherd's Purse, where the septum is in the narrow plane of the fruit (Fig. 215, C).

A sharper angular bend, or keeling of the leaf at the midrib, gives the condition found in Penny-cress (Stinkweed), where the septum is at its narrowest (Fig. 215, D).

In the siliqua and silicula the seeds are borne on thickened marginal placentas which are connected by the septum. These placentas form a sort of framework, which is called the *replum*.

The replum is seen well in Honesty as it is sold in the streets in autumn (Fig. 215, B). The fruit coat is no longer there, but the septum persists and is the flat, silvery ornamental part. The framework round this is the replum. Impressions of the seeds are often seen on the septum, and often, too, seed-stalks are still attached to the replum and lie flat upon the membrane.

Typical siliquas occur in Wallflower, Worm-seed Mustard, and Stock (Fig. 215, A).

In Shepherd's Purse, Candytuft, and Sweet Alyssum the fruit is a silicula (Fig. 215, C).

In both types dehiscence takes place by separation of the valves from below upwards (Fig. 215, A).

Schizocarps.

A *schizocarp* is a fruit formed from a syncarpous pistil. In the process of maturing it divides into separate parts, the number of these being generally determined by the number of carpels. Each part into which the schizocarp divides is called a *mericarp*. It contains one seed and closely resembles an achene.

There are two mericarps in the double samara of the Sycamore and of the Manitoba Maple (Fig. 219), and in all the fruits of Umbelliferæ to which the Caraway and Wild Parsnip belong (Fig. 216, A).

In the Garden Nasturtium the schizocarp divides into three.

These mericarps are put into salads and may be used instead of capers for making sauce (Fig. 216, B).

The four mericarps of the White Dead Nettle result from a pistil composed of only two carpels (Fig. 216, C).

In the Geranium there are five mericarps (Fig. 216, D) and in the Hollyhock and Mallow the number is indefinite (Fig. 216, E).

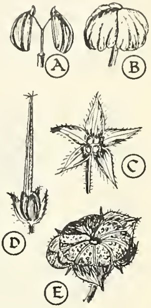


Fig. 216.—Schizocarps. A, Two mericarps: Wild Parsnip. B, Three mericarps: Garden Nasturtium (Tropæolum). C, Four mericarps: White Dead Nettle. D, Five mericarps: Herb Robert. E, Many mericarps: Hollyhock.

Juicy Fruits.

A *drupe* is a juicy, one-seeded fruit in which the pericarp consists of three layers: epicarp, mesocarp, and endocarp (Fig. 213, B^1). It occurs in many members of the Rosaceæ, as in the Plum, Cherry, Apricot, and Peach.

In the Almond, which also belongs to Rosaceæ, the drupaceous character is not so obvious because, in Almonds as we buy them, only the endocarp and the enclosed seed remain. This gives the general impression that the Almond is a nut. The epicarp and mesocarp are familiar to all who have Almond trees in the garden, for, even in England, some fruits are formed each year. The epicarp is green and rather plush-like. The mesocarp has by no means the juicy character of the Plum and Cherry.

The Walnut and Coco-nut are other rather unrecognisable drupes. They do not belong to Rosaceæ.

In pickled Walnuts the drupe-like character of the fruit is obvious. As they are sold by the grocer they, like the Almond, consist of endocarp and seed only.

The Coco-nut, too, has its epicarp and mesocarp removed before it is offered for sale.

The epicarp is thick, tough, and shiny. It makes a waterproof cover for the fruit when it is being carried by the waves.

The mesocarp in this case is not at all juicy. It is, on the other hand, very fibrous and is used for making Coco-nut matting. The waste from this process is the fibre sold for growing bulbs. Its value for this purpose depends upon the fact that it holds so much air. This makes it quite a difficult matter to mix the dry fibre with water. This quality of the mesocarp helps greatly in buoying up the fruit when it falls from the palm tree to the sea.

The hard brown endocarp of the Coco-nut has three dints at one end. One of these is so soft that a hole can easily be made to let the milk escape. The dints are germ pores, but now only one embryo develops in the Coco-nut, so two of the germ pores are permanently closed. The very small root lies in the very large seed close to the functional germ pore of the endocarp.

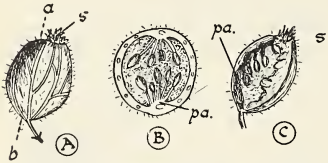


Fig. 217.—Gooseberry. A, Entire berry. B, Cross-section of fruit. C, Longitudinal section of A, in the plan *a.b.* *pa.*, placenta (parietal placentation); *s.*, old calyx (superior).

In a *berry* the whole pericarp except the outside skin becomes succulent.

In the Tomato, Orange, and Grape, the berry is formed from a superior ovary.

The Gooseberry, Currant, Vegetable Marrow, Cucumber, and Banana are all inferior (Fig. 217).

In the Banana vegetative propagation has reached such a degree of perfection that in the cultivated species seeds do not develop. All that remains of them is a sort of brown dustiness, occasionally seen in the centre of the fruit.

A Date is a berry with one seed only. The reserve food in this case is stored up as cellulose, and that is why the date-stone, or seed, is so hard all through. The date " stone " is in no way comparable to the " stone " of a drupe.

In the seed of one species of palm the cellulose store is so great and so hard that it may be carved into little figures. It is sold as vegetable ivory.

The *pome* has already been described (p. 365). The true fruit of the Apple and Pear is the core. The succulent tissue that encloses the core is the stem or receptacle and the external skin is the epidermis of the stem (Fig. 218).

The fruit of the Hawthorn is difficult to place. It is variously described as a berry, a drupe, or a pome.

Aggregate Fruits.

A flower can only produce a collection of fruits when its pistil is made up of free carpels. As the apocarpous pistil is characteristic of Ranunculaceæ and Rosaceæ, collective fruits are found in these families.

In Ranunculaceæ the fruits of Delphinium, Monkshood, and Columbine, of the Peony, Christmas Rose, and Kingcup (Marsh Marigold) are collections of follicles (Fig. 200). The fruits of all the Buttercups, of Clematis, and Anemone are collections of achenes (Fig. 222).

In Rosaceæ there are heads of achenes in the Rose, Avens (Geum), and Strawberry (Fig. 211). The Raspberry, Blackberry, and Loganberry are not "berries" at all, but collections of very small drupes, called *drupels* (Fig. 213, B).

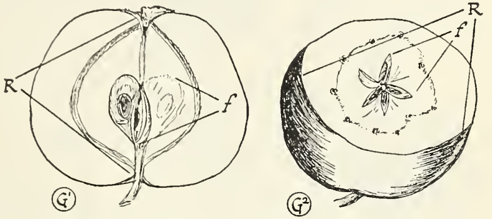


Fig. 218.—The Pome. G¹, Longitudinal section. G², Transverse section of apple "fruit." *f.*, true fruit (*core*); *R*, receptacle greatly developed after fertilisation.

Dispersal of Seeds.

When fertilisation has taken place in the flower, so that the ovule has become a seed and the ovary a fruit, the next consideration is the satisfactory distribution of the seeds. There must, of necessity, be a good deal of waste in all operations that take place on a very big scale, but if seeds simply dropped from fruits in a haphazard way, the waste would be so excessive as to be a very serious matter. Such a state of overcrowding would result that very few young plants would survive. They would struggle one against another for space, food, and air, and, in the case of woody perennials, the parent plant would be a most formidable competitor.

For this reason more or less adequate adaptations with a view to efficient seed-dispersal are found. These may be adaptations of the fruit or, in a many-seeded fruit, of the seeds themselves, so that separation of the seeds is effected.

One of the most important external agents in seed-dispersal is wind. Appendages in the forms of hairs and wings are found on many fruits and seeds and give a certain buoyancy that greatly aids the carrying power of the wind.

Dispersal by Wind.

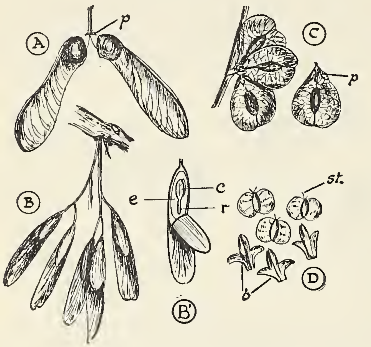


Fig. 219.—Winged fruits (samaras). In each case the wing is an expansion of the fruit-coat. A, Sycamore, showing the splitting of the schizocarp into two mericarps. B, Ash. C, Elm. D, Birch. *b.*, bracts; *c.*, cotyledons; *e.*, endosperm; *p.*, remains of perianth; *r.*, root; *st.*, stigma.

Winged Fruits.

In fruits the wing may be a modification of the pericarp. The formation of the wing depends upon the expansion and flattening of the pericarp during development, except in the area that encloses the seed. Such a fruit is called a *samara* (Fig. 219).

The Ash and Elm are single samaras. The Birch is a single samara, but each fruit has a divided wing. The three-pointed leaves, rather like scout badges, which are found among Birch fruits are bracts, in the axil of each of which three flowers grew (Fig. 219, D).

The Sycamore fruit is a double samara and divides before dispersal into two mericarps (Fig. 219, A). It is only necessary to fling a mericarp up to the ceiling to realise the help given by the wing in dispersal. The spin results from the fact that the wing is heavy on one side and light on the other. A similar fruit occurs in the Manitoba Maple (Box Elder).

In some fruits the wing is formed by persistent bracts which, unlike those of the Birch, remain attached to the fruit. Three joined bracts remain in connection with the nut of the Hornbeam and help in its dispersal (Fig. 220, A). In the Lime the axis of the inflorescence is firmly attached to a long slender bract for nearly half its length (Fig. 220, B). In this case the bract keeps rain from reaching the pollen when the flower is out; when the flower is succeeded by the fruit it serves as a wing to help in dispersal.

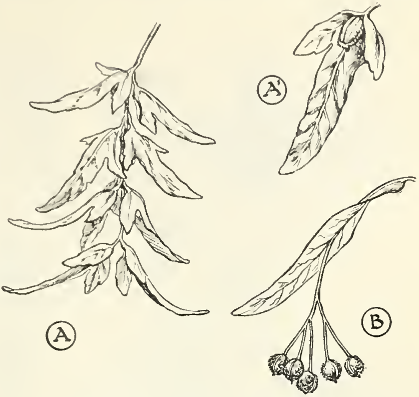


Fig. 220.—Winged fruits. A, Cluster of fruits of Hornbeam. A¹, One fruit. The wing surrounding the nut is formed from three bracts. B, Lime (Basswood) fruits. The wing is formed from one bract.

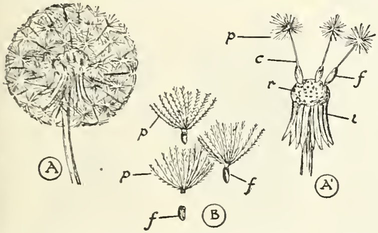


Fig. 221.—A, Head of Dandelion fruits (cypselas). A¹, Naked receptacle. B, Thistle fruits with sessile pappus of branched hairs. *c.*, column that grows after fertilisation; *i.*, involucre of bracts; *f.*, fruit; *p.*, pappus; *r.*, receptacle.

Hairy Fruits.

When a fruit is provided with hairs these may be in the form of a *pappus*, as in many of the Compositæ, where the calyx is often represented by this ring of hairs.

In the Dandelion the pappus is supported by a slender column and acts like a parachute (Fig. 221, A¹). In Thistles the pappus, whose hairs are branched, rests on the apex of the fruit without the intervention of a column

(Fig. 221, B). Thistle fruits float very lightly on the air. Their attachment to the pappus is so slight that a roughness in the breeze, or any contact, is enough to separate them. The fruit then falls to the ground and, as thistledown, the pappus floats away. In all probability this accounts for the fact that Thistles so often grow under walls and hedges, which have acted as obstacles to the floating fruits.

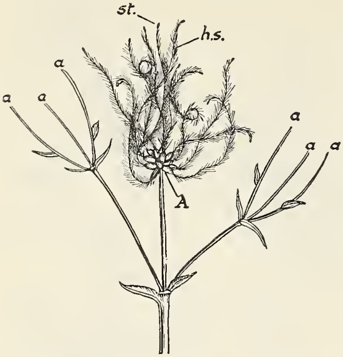


Fig. 222.—Wild Clematis (Traveller's Joy. Old Man's Beard). A, Cluster of achenes resulting from one flower. *a.a.*, position of similar clusters ; *h.s.*, hairy, persistent style ; *st.*, old stigma.

In some cases fruits owe their lightness to numerous hairs which grow from persistent styles. Traveller's Joy, or Old Man's Beard, is one of the best-known examples of this method of dispersal (Fig. 222). A familiar Canadian example is the Pasque Flower or so-called Prairie Crocus.

It is extremely important not to confound fruits and seeds. In the foregoing examples the special aid for dispersal is some adaptation of the fruit itself, the seed being carried within the fruit.

Winged Seeds.

Similar adaptations occur in seeds. As might be expected, the expansion and flattening of the testa make a serviceable wing. Beautifully lobed wings are formed in this way in Bignonia seeds. Bignonias are tropical

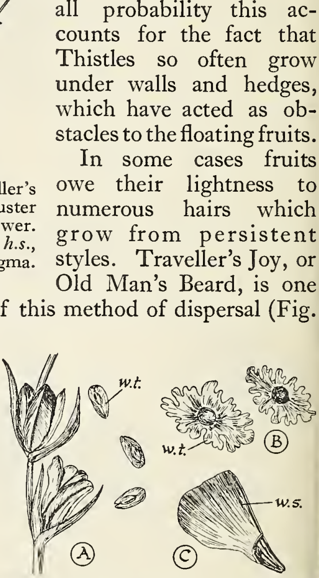


Fig. 223.—Winged seeds. A, Capsules and seeds of Gladiolus. B, Seeds of Bignonia. C, Cedar seed. *w.s.*, wing formed from scale of cone; *w.t.*, wing formed from testa.

plants, but it is possible to get their seeds from many parks and botanical gardens (Fig. 223, B). From our own flower-beds we can collect the fruits of Gladiolus and see the winged seeds within the capsule (Fig. 223, A).

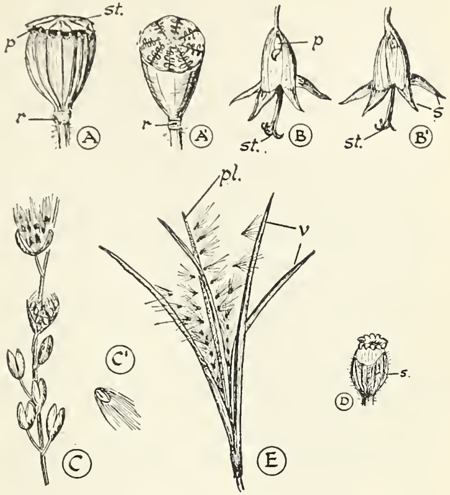


Fig. 224.—A, Capsule of Poppy, opening by pores. A¹, Transverse section of the same, showing parietal placentation. B, Capsule of Campanula, showing one of the three open pores. B¹, The same with the pores closed against rain or heavy dew. C, Capsules of Poplar in various stages of dehiscence; C¹, One seed of Poplar, showing the aril of hairs. D, Capsule of Campion, opening by teeth. E, Capsule of Greater Willow-herb, opening by valves. In this case the hairs on the seed grow from the testa. *p.*, pores; *pl.*, placenta; *r.*, scar left by sepals, petals, and stamens; *s.*, persistent calyx; *st.*, old stigmas; *v.*, valves.

The wing of the Pine, Spruce, Cedar, and allied seeds is formed quite differently (Fig. 223, C). It is a thin, membraneous detachment from the inner part of the cone-scale, upon which the seed lies. An ovule of the Pine may miss fertilisation, but the wing still becomes detached from the cone, ready to buoy up a seed that will never be formed. Pine kernels, detached from the wings, take the place of Almonds on the cheaper Dundee cakes.

Hairy Seeds. Delicate hairs that help in seed-dispersal are in some cases outgrowths of the testa. To see them to the best advantage a fruit of Greater Willowherb (Fireweed) should be carefully opened (Fig. 224, E). The most satisfactory way is to hold the short stalk of the capsule between the finger and thumb of one hand and, with the other, give a pinch and a slight twist to the apex of the inferior fruit, just by the scar of the fallen petals. The fruit then begins to split by four valvular openings and reveals a marvellous instance of packing. The column that stands erect in the centre of the open capsule is the placenta to which the seeds were attached.

The cotton of commerce is obtained from the long hairs on the seeds of the Cotton plant.

In other cases hairs grow at the base of seeds and are not developed until after fertilisation. They are, therefore, of the nature of an aril (p. 382). The dispersal of Poplar and Willow seeds depends upon such an aril of hairs (Fig. 224, C).

On the whole the development of winged and hairy appendages on fruit and seed is effectual in securing a fairly wide range of distribution. Where dispersal consists in nothing more than the shaking of the ripe fruit, the scattered seeds fall over a very limited area. It is, however, a sufficiently good method for annuals.

Censer Mechanism.

This method, known as censer mechanism, is well seen in the Poppy (Fig. 224, A). The long, stiff fruit-stalk waves in the breeze; the seeds inside the capsule have become detached from their parietal placentas and are shaken out of the pores at the top of the fruit. This method is by no means limited to annuals. It occurs in biennials and perennials also, as in Foxglove and Snapdragon.

There is an ingenious device in different Campanula (Canterbury Bell) capsules, which open by three to five pores. The fruit of some species is erect and then the pores are at the top, close under the persistent calyx. In others the fruit droops and the pores are at its base (Fig. 224, B). In either case the pores are uppermost in space and, therefore, more force is required to expel the seeds and they are more wide-flung. There is, here, the apparent danger of rain entering the capsule and wetting the seeds, because of this position of the pores. The walls of the capsule, however, are very hygroscopic, that is, very sensitive to moisture, and the pores close at once in damp weather.

In some cases seeds are so light that no additional device is necessary to secure their dispersal. In Orchids they are blown out of the three openings in the capsule like fine dust.

Light Seeds.

Dispersal by water is not nearly so common as one might suppose. The extremely buoyant fruits of Water Lilies, for instance, rest on the surface of ponds. But this is stagnant water, and the actual movement of the fruit depends upon wind.

Dispersal by Water.

Some plants that grow by the sides of streams drop their fruits or seeds into the water. This often happens in the case of Alders. Sometimes the seeds are carried by the current and lodge in a more distant part of the bank. But, speaking generally, in such cases the fruits and seeds get water-logged and sink. Coco-nuts are certainly carried by waves from one island to another, and this explains the palm-girt character of the islands. This is a highly specialised case.

Actual dispersal by water does take place when seeds of wall- and rock-plants are carried in trickles of rain and lodge in a crevice some little distance from the parent plant. Seeds of Snapdragon, growing on old walls and chalky cliffs, of Wallflowers on old walls, of Herb Robert, also on old walls, are all dispersed in this way.

For dispersal over a really wide area, animals, especially birds, are largely responsible. Web-footed water-birds carry seeds in the mud that clings to their feet. Other birds, jackdaws, swallows, and wagtails, often get smeared with mud. Later, when they preen their feathers and clean up their feet, the dry mud, with any seeds it may contain, falls to the ground, probably at a distance from the original place of contact.

Dispersal by Animals.

In his very careful investigations, Darwin removed $6\frac{3}{4}$ ounces of mud from water-fowls and mixed it with sterilised soil. From this $6\frac{3}{4}$ ounces, 537 plants germinated.

Our own gardens show how very frequently fruits must be dropped by birds in flight. Oak, Hawthorn, and Beech seedlings spring up in suburban gardens of England, often far from the trees that bore them.

Some fruits and seeds are expelled in the excretions of birds.

This implies that the fruits have a very hard pericarp or the seeds a very hard testa, so that these coats resist digestion in their passage along the bird's alimentary tract. Numbers of hard seeds are dispersed in this way by thrushes and blackbirds especially. The missel-thrush gets its name from its connection with Mistletoe. It eats the viscous fruits and expels the undigested seeds. Probably this accounts for the almost invariable position of Mistletoe, which hangs from the undersides of the branches of Apple and Poplar in Europe. The excretion of thrushes is extremely liquid ; it trickles down the curve of the branch and lodges the seed in the crevice of the bark towards its lower surface.

It is just possible that in some few cases dispersal may depend upon neglected food-stores. The squirrel and jay make stores of fruits and seeds for use in the barren winter months. If these are forgotten, or if the animal dies, germination may take place. But, for the most part, these stores are too crowded to be regarded as an effective means of dispersal.

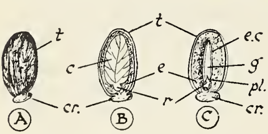


Fig. 225.—Castor Oil. A, Seed. B, Seed cut in the plane of the cotyledons. C, Seed cut in a plane at right angles to B. *c.*, cotyledon ; *cr.*, caruncle ; *e.*, endosperm ; *e.c.*, cut edge of cotyledon ; *g.*, cavity in endosperm ; *pl.*, plumule ; *r.*, radicle ; *t.*, testa.

Another proverbially provident animal in the matter of food stores is the ant. Ants are particularly attracted by seeds which have, at the base, a little partial aril called a *caruncle*. The seeds of Violet, Periwinkle, and Greater Celandine all have such a caruncle. The ants labour along, collecting their store, seed by seed. At the end they eat nothing more than the caruncle, so that the seed itself is unharmed and germinates.

Apart from this, the value of the caruncle is not very evident. It is supposed, in some cases, to absorb water in a sponge-like way and pass it to the micropyle, which lies near it. This may be so in the Castor Oil where the testa is very resistant (Fig. 225).

An *aril* is an additional covering to a seed. It develops after fertilisation has taken place. Very obvious arils are the bright red, juicy coverings that occur on the Yew, " threading it with colour " (Fig. 226). The Spindle seed, too, has a bright orange aril contrasting strongly, when the fruit dehisces, with the pink pericarp. In these cases, without doubt, the aril is attractive to birds, which expel with their excretion the undigested seeds.

A more highly organised plan for dispersal by animals is found in those numerous fruits that are provided with adhesive appendages in one form or another. Kerner estimates that " about 10 per cent. of all Flowering Plants possess fruits or seeds which are dispersed by means of clawed or barbed processes."

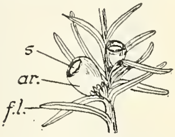


Fig. 226.—Yew. *ar.*, aril; *f.l.*, foliage leaf; *s.*, *seed.*

On the elongated receptacle of Geum (Avens) the achenes have long, hooked styles. Originally the styles were straight. Later they form a loop. Later still the loop breaks in such a way that a hooked end remains (Fig. 211).

In Goosegrass stiffly re-curving hairs, like those that help the stem to climb, occur all over the two halves of the schizocarp (Fig. 163). Similar hairs develop on the mericarps of Enchanter's Nightshade. After walking through the undergrowth of a wood these small burrs may be found in dozens clinging to one's stockings.

The burrs of the Burdock are quite different morphologically, for hooks are not developed on the fruits. Burdock belongs to Compositæ, and each bract of the involucre curves sharply back at the tip (Fig. 227, b^1). Thus the numerous small black cypselas are surrounded by a chaplet of hooks. The hairs of the imperfect pappus are extraordinarily irritant. It is unwise to let them touch the face or neck, for they cause a burning that is quite disagreeable.

The burrs in Agrimony are different again. Agrimony is a member of Rosaceæ and shows such extreme perigyny that it becomes, as in the Apple, epigyny. In this case the true fruit is only one-seeded, so the fruit is a sort of inferior nut. The burr results from the stiff hooked bristles that grow from the receptacle (Fig. 227, A^1).

In the Bur-marigold, which is a Composite, two or more stiff spikes, representing the calyx, project from the top of the fruit. These are barbed and cling tenaciously to any object with which they come in contact (Fig. 227, C^1).

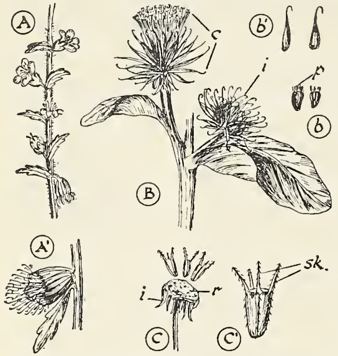


Fig. 227.—Fruits with adhesive appendages. A, Part of inflorescence of Agrimony. A^1, One fruit, with strong de-curved hairs on the receptacle. B, Burdock. C, Receptacle and fruits of Bur-marigold (Bidens). C^1, One fruit (cypsela) enlarged. *b.*, fruits of Burdock (cypselas); b^1, hooked bracts; *c.*, capitulum; *i.*, involucre; *p.*, pappus; *r.*, receptacle; *sk.*, barbed spikes that represent the calyx.

All these barbed fruits may get fixed in the coats of passing animals, to be set free in some more distant area.

Explosive Mechanism.

Many cases of seed-dispersal depend upon some mechanism in the fruit. An extreme case is that of the Squirting Cucumber. When this separates from its stalk a hole remains at the point of junction. The expansion of a particular layer of tissue within the fruit causes so much pressure that the seeds, and all the mucilage surrounding them, are shot out of the hole with force.

Among our own plants similar phenomena, but of a milder nature, are met with. Violent expulsion of the seeds of the Wood Sorrel is brought about by a layer of cells on the inner side of the aril of each seed; this swells and thus imposes a great strain on the outer layers. The result is a sudden slit in the outer region of the aril, a swift rolling back of the slit edges, and the jerking of the seed from the fruit.

In the Balsam (Touch-me-not), the Bitter Cress, and

Violet the expulsion is due to a rupturing of the fruit coat, as a result of inequality in stresses and strains (Fig. 228, C).

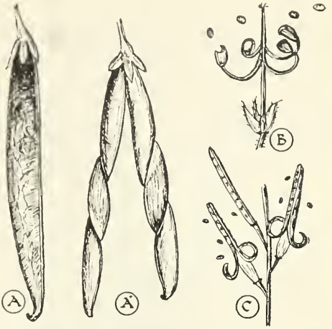


Fig. 228.—Explosive fruits. A, A¹, Closed and open pods of Everlasting Pea. B, Splitting schizocarp of Herb Robert (Geranium). C, Dehiscing siliquas of Bittercress.

In Geraniums the fruit is a schizocarp. The separation of the mericarps follows the lines of union of the five parts of the style. The rupture is sudden and begins from below, so that each released strip curves outwards and rolls up. As the rolling is a sudden process the seeds are flung out with a jerk, as a stone is flung from a catapult (Fig. 228, B).

In many Leguminosæ, seeds are expelled by a twisting of the two halves of the pod at the time of dehiscence (Fig. 228, A¹). Sitting near Gorse bushes on a summer day about noon, one hears repeated little pops, each followed by a rustle. The pop is the sudden opening of the pod. The rustle is the contact of the flung seed with the undergrowth.

CHAPTER XXVI

SEEDS AND GERMINATION

THE seed which, in one way or another, reaches the ground to germinate, has a protective coat, or testa. Within this is the embryo, or rudimentary plant. A reserve food supply is absolutely essential for the use of the embryo when first it begins to grow. In some seeds this store is contained in the embryo itself. In others it occupies an independent position and is then known as *endosperm*.

The Broad Bean seed is so big and so cheap, and the seedling does all that is required of it in such an exemplary fashion, that we naturally turn to it for preliminary study.

The seed is made up of two parts. The first of these is the *testa*. The second is all that is within the testa and is, in this case, the *embryo*, and the embryo only.

The Broad Bean Seed.

The testa is of a uniformly drap colour, broken by a sharply defined, long black band at one end. This mark is the *hilum* and denotes the region where first the ovule, and later the seed, was attached to the *funicle*, the boat-shaped stalk that formed the attachment to the pod (Fig. 229).

On the curved rim of the seed, above one end of the hilum, a triangular bump marks the position of the radicle. Between the apex of the bump and the end of the hilum there is a minute hole, or *micropyle*, through which the pollen-tube entered the ovule in fertilisation. The presence of this hole is made obvious by soaking the seed in water for forty-eight hours. Gentle pressure near the hilum will now cause drops of water to exude from the micropyle. It is obvious that the hole is well placed in relation to the tip of the radicle that must, sooner or later, emerge.

In such soaked seeds it is an easy matter to remove the testa whole, when its tough character is evident. On one curve there is an inner pocket into which the radicle fits. The radicle is in a somewhat unprotected position because of being so near the micropyle, which is an area of weakness, and this pocket gives it extra protection.

When the testa is removed the naked embryo is fully exposed. It consists of three parts (Fig. 229, B):

The Embryo.

(1) Two seed-leaves, or *cotyledons*, which are attached laterally to a very short primary axis.

(2) The *radicle*, or young root, which points directly downwards from the primary axis.

(3) The *plumule*, or rudimentary bud, which grows directly upwards from the primary axis. It lies between the cotyledons at right angles to the radicle. The plumule develops into the plant's whole system of leaf-bearing, flower-bearing, and fruit-bearing parts.

Clearly the stem is not an upward continuation of the root, any more than the root is a downward prolongation of the stem. In the early cell divisions which follow the fertilisation of the egg, certain cells are marked off to become the plumule, or shoot, while others are destined to form the root.

The Food Store.

Testing with iodine shows that the cotyledons contain large quantities of starch. In this test it is interesting to scrape one cotyledon and leave the other intact, in order to see the resistance provided by the protective epidermis.

To prove the presence of protein the cotyledons should be well crushed with water.

One portion turns red when tested with Millon's reagent and boiled (p. 161).

Another portion should be subjected to the nitric-acid test. When the crushed mass is treated with concentrated nitric acid it turns yellow on warming. When the acid is replaced with ammonia a bright orange colour results.

The Biuret reaction gives a very pretty test for proteids. If the remaining portion of the crushed cotyledons is treated, first with 1 c.c. of 40 per cent. caustic soda solution, then with a drop of 1 per cent. copper sulphate solution, a violet colour is produced.

Germination of the Broad Bean.

There is, then, ample provision in the cotyledons for the needs of the seedling. It only remains for the stores of starch and proteins to be made available for absorption by the root and shoot. Given a suitable temperature and a supply of water, cells of the embryo secrete enzymes that bring the stored foods

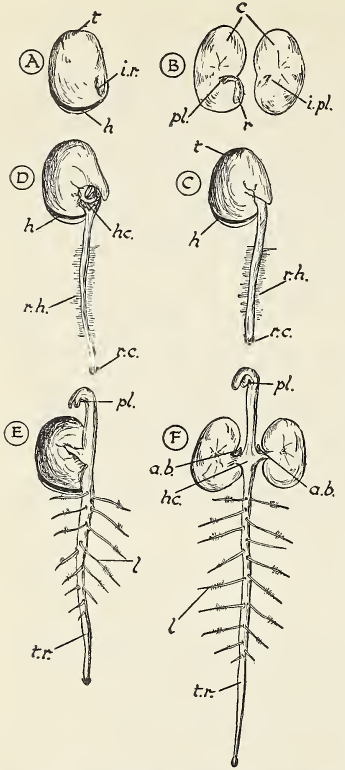


FIG. 229.—Broad Bean seed and seedlings. A, Seed. B, Embryo with cotyledons separated. C, 4-days-old seedling. D, E, F, seedlings 6, 8, and 14 days old, respectively. *a.b.*, axillary bud; *c.*, cotyledons; *h.*, hilum; *hc.*, hypocotyl; *i.pl.*, impression of pl.; *i.r.*, bulge of radicle; *l.*, lateral root; *pl.*, plumule (first bud); *r.*, radicle; *r.c.*, root-cap of main root; *r.h.*, root-hairs of main root; *t.*, testa; *t.r.*, tap-root.

into this condition. The work of one class of enzymes is to break down the cellulose walls of the cells of the cotyledons and so prepare the way for the enzyme *diastase* which changes the starch into sugar. The proteins, in their turn, are also brought into soluble form.

In germination the pressure of the growing root tears the testa at the point of weakness and its tip emerges in the region that was once the micropyle (Fig. 229).

When the root is well established in the ground, the plumule grows up. Its tip is bent like a crochet-hook, so that the delicate leaves of this first bud are not subjected to friction (Fig. 229, E). Once the tip has broken through the surface of the soil it becomes erect by the straightening of the stem.

The first leaves borne on the stem are simply stipules (Fig. 230, A). These are succeeded by compound leaves made up of two leaflets and a rudimentary tendril. At the base of each compound leaf is a pair of stipules. The later leaves have three pairs of leaflets and the rudimentary tendril is still present.

The elongation of the stem of the plumule, the primary bud of the plant, like the corresponding elongation of the axis of a resting-bud, separates the nodes widely. The leaves, which were originally crowded together, are now separated one from another by long internodes, and the only crowding is that of the young leaves, continually being formed from the growing point (Fig. 230, A).

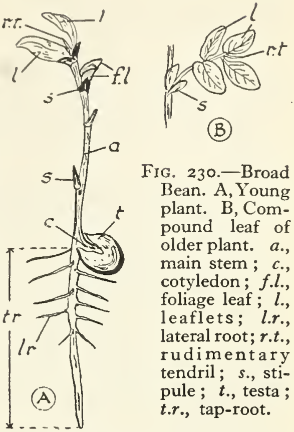


Fig. 230.—Broad Bean. A, Young plant. B, Compound leaf of older plant. *a.*, main stem; *c.*, cotyledon; *f.l.*, foliage leaf; *l.*, leaflets; *l.r.*, lateral root; *r.t.*, rudimentary tendril; *s.*, stipule; *t.*, testa; *t.r.*, tap-root.

It is at this stage of growth that doubt as to the morphological nature of the cotyledons disappears. They look remarkably un-leaflike as they lie within the testa. Now, if the testa is removed and the cotyledons opened out, a bud is seen in the angle that each cotyledon makes with the axis. The presence of these axillary buds proves, beyond doubt, that the cotyledons are really leaves. If the main shoot is injured in germination one, or both, of the buds develops in its stead.

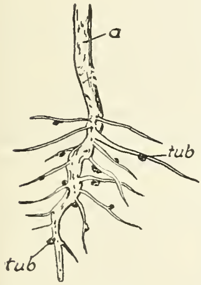


Fig. 231.—Root of Broad Bean. *a.*, stem; *tub.*, root tubercle.

There is a difference in internal structure between root and stems. The area in which the change from one to the other takes place is called the *hypocotyl*. In the Broad Bean this area, below the cotyledons, is extremely short (Fig. 229, F).

Even when the root has penetrated the soil the reserves in the cotyledons are still being used as food. The seedling has, in fact, no other supply, for it is not until the leaves are well expanded that the new plant can carry on the work of photosynthesis (p. 308).

A proof that the cotyledons do supply the food is gained by very carefully cutting them away from a seedling, leaving the elongating radicle and plumule in the moist air of the gas-jar. There is no further development, and both root and shoot die.

The same truth may be demonstrated by a comparison of weights.

A completely dry seed must be weighed before it is soaked in distilled water. After soaking it is allowed to germinate in a gas-jar with blotting-paper and distilled water, the growth continuing until both root and shoot are several inches in length. These are then most carefully cut off quite close to the testa. The testa and what remains of the cotyledons within it are then allowed to become just as dry as was the original seed before soaking. In this state it is weighed, and this second weight is found to be appreciably less than the first, showing that food from the cotyledons has been used in the building up of root and stem. Of course, in weighing the original seed the weight of radicle and plumule is included; but even when allowance is made for these very minute structures the difference in weight is marked.

Actually these somewhat elaborate experiments are not necessary to prove the point. Seedlings in gas-jars in the dark grow greatly. Their leaves cannot make food in the dark. There is nothing in the way of nutrition to be got from distilled water. If the food necessary for growth was not provided by the cotyledons, what other possible source was there?

Conditions necessary for Germination.

It is only common sense to suppose that seeds will not germinate unless they are provided with air, moisture, and a certain degree of temperature. It is easy to prove that this is really so by depriving seeds in turn of these conditions and noting the result. Barley, Oats, Cress, and Mustard seeds may all be experimented with in this way.

Instead of using blotting-paper, a layer of cotton-wool is put at the bottom of four clean gas-jars. In one dry seeds are sprinkled on the dry cotton-wool and the jar is kept in an ordinary warm place. The seeds have plenty of air, a moderate temperature, but *no moisture*. The result is that germination does not take place.

In the remaining gas-jars soaked seeds lie upon damp cotton-wool.

Water that has been boiled to expel air, and then allowed to cool, is added to one set of seeds, until the jar is a little less than half full. A layer of oil on the top prevents air from coming into contact with the water from without. In this case the seeds have plenty of water, but *no air*. Again they do not germinate.

The third gas-jar stands in a pneumatic trough, packed round with ice. Air and moisture are both available, but *the cold prevents germination*.

The fourth jar stands on a bench in the laboratory and the seeds germinate. They are provided with air and moisture and are at the ordinary room-temperature.

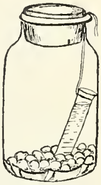


FIG. 232.—Experiment to demonstrate the respiration of germinating peas.

Respiration of Germinating Seeds.

The need for air depends upon the fact that every living thing must breathe. Respiration experiments on mature plants have to be conducted in the dark because, in the light, their green leaves give out oxygen and use up carbon dioxide in the work of photosynthesis. Experiments relating to the breathing of seeds can be carried out openly in the laboratory, because there are no green leaves, in this case, to complicate the gaseous interchange.

As respiration includes both the giving out of carbon dioxide and the taking in of oxygen, the experiments must be conducted with both these processes in mind.

Soaked peas are eminently satisfactory for use in these demonstrations. In the first experiment they should be put into a flask, on the bottom of which are two or three layers of damp filter paper. A test-tube of lime-water is let down into the flask by a cotton thread and the flask is corked (Fig. 232). The next day the lime-water is milky, just as if it had been breathed into by ourselves. The "milkiness" is fine particles of chalk suspended in the water, because the following chemical reaction has taken place :

$$\underset{\text{caustic soda}}{CO_2 + Ca\,(OH)_2} \rightarrow \underset{\text{chalk}}{CaCO_3} + H_2O.$$

An additional proof that the peas have given out carbon dioxide is gained by putting a burning taper into the flask. The flame is extinguished the moment it enters the neck of the flask. The peas have given out carbon dioxide ; the air in the flask no longer supports combustion and the lime-water has become milky.

The extinguishing of the taper suggests that the oxygen originally present in the flask has been used up. To prove that this is so a flask and soaked peas are arranged as before, but a test-tube of strong caustic potash solution takes the place of lime-water. The cork is replaced by a one-holed rubber stopper, through which passes a glass tube bent at two right angles. The long vertical arm of the tube dips into a beaker of some coloured solution.

Along with the peas in the flask there are, originally, nitrogen, oxygen, and a little carbon dioxide. The original carbon dioxide is absorbed by the potash. Assuming that the peas do breathe they will use the oxygen in the flask and give out carbon dioxide. But this will at once be absorbed by the potash, with the result that the volume of gases in the flask is reduced. This tendency to form a partial vacuum is counter-balanced by the air in the bent glass tube entering the flask. But naturally the drawing in of the air is followed by the drawing up of the coloured solution, which rises rapidly in the long vertical arm of the tube, to take the place of the oxygen used by the peas.

Hence : germinating seeds take up oxygen and give out carbon dioxide. That is, they breathe.

Intramolecular Respiration.

Intramolecular respiration of plants has already been referred to (p. 254). It can be demonstrated by using peas. A very small test-tube is necessary or, better still, one of the small specimen tubes that the dealers use when they supply Amœba and Chlamydomonas.

The tube, filled with mercury, is inverted in a small dish of mercury and clamped vertically. Four or five soaked peas have their testas removed and are then inserted, one by one, into the mouth of the tube. The light seeds rise quickly in the dense mercury to occupy positions at the upper end of the tube. There is no gas of any kind in the inverted tube, because it was first of all completely filled with mercury. No air has been admitted with the peas because the precaution was taken of removing their testas, lest there should be a little air between these and the embryos.

As the days pass the mercury sinks gradually lower in the inverted tube and the peas are now seen resting upon it, occupying a clear space in the tube (Fig. 233). The sinking continues until the whole of the mercury has left the tube. It is plain that something must have forcibly pushed out the heavy mercury; that this invisible "something" must be a gas; that it must have come from the peas, because there is absolutely nothing else present that could have produced it.

The tests for this gas must be conducted very carefully; there is so little present in the very small tube that one cannot afford to waste any.

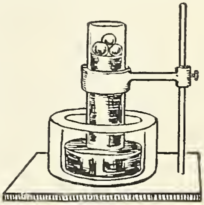


FIG. 233.—Experiment to prove that intramolecular respiration takes place in germinating peas.

Carbon dioxide is heavier than air. In removing the tube from the clamp, therefore, the thumb must securely cover its mouth and the tube must be inverted as quickly as possible. There is no room for a test-tube of lime-water this time, so a drop of clear lime-water, hanging from the end of a glass rod, must be brought to the mouth of the tube. It becomes quite definitely milky. When a burning match is put into the tube the flame is at once extinguished.

There is, then, no room for doubt. The peas have given out carbon dioxide; they have carried out one half of the breathing process. As they were supplied with no oxygen from without, the only possible source from which they could derive it was their own tissues. It is this process, in which plants use the oxygen actually within themselves in breathing, that is known as *intramolecular respiration.*

The degree of temperature below which seeds will not germinate is, naturally, not constant. The seeds of tropical plants will not germinate unless they have much more warmth than is required by peas and beans and hardy Northern plants generally. There is, in fact, for all plants a certain *optimum temperature*, at which germination most readily takes place.

Temperature and moisture together give the stimulus for the secretion of the enzymes that are essential for changing the reserve foods into an absorbable form. Water is taken in all over the testa and the first effect of absorption is to cause the seed to swell. This is really swelling, not growth. Growth is a permanent change of form, but if the swollen seed be allowed to dry it shrinks, gradually, to its former size. The pressure exercised by swelling seeds is known as the force of *imbibition*, and is surprisingly great. It is only necessary to put some dry peas, with water, in a test-tube to realise the truth of this. As the seeds swell the test-tubes are splintered. The use of swelling peas in skull-dissection has already been indicated (p. 217).

In the germination of a Broad Bean the cotyledons always remain below the ground. This is known as a *hypogeal* condition. It is not nearly so usual as the *epigeal* type of germination, in which the cotyledons come up above the soil-level as the first green leaves of the plant. When the seeds that we have sown in the garden " come up " it is the paired cotyledons that are seen making the green pattern above the soil.

The Kidney Bean.

In the French or Kidney Bean the cotyledons are epigeal. The structure of the seed is similar to that of the Broad Bean in all essentials, but there are differences of detail. The plumule is perhaps a little more *feather*-like and the radicle and plumule occupy a different position, so that the micropyle is also differently placed (Fig. 234).

In the germination of the Kidney Bean it is a simple matter to determine the value of the cotyledons, for when they are well up above the coco-nut fibre they can be cut off from two or three plants. These plants invariably die, being deprived of their food supply, while the others grow sturdily for some time.

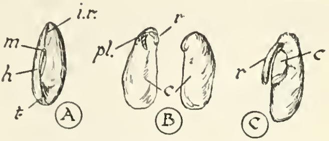


Fig. 234.—French Bean. A, Seed. B, Seed with testa removed and cotyledons separated. C, Seed germinating. *c.*, cotyledon ; *h.*, hilum ; *i.r.*, bulge of radicle ; *m.*, micropyle ; *pl.*, plumule ; *r.*, radicle ; *t.*, testa.

As the plumule in the seed lies between the cotyledons, it is between the cotyledons that the shoot must be looked for in the seedling. The long, elongating axis cannot, therefore, be any part of the shoot. It is, in fact, not stem at all, but the elongated hypocotyl (Fig. 235). In all cases of epigeal germination the hypocotyl elongates in this way and the plumule unfolds between the two protecting cotyledons. Before they drop off, the cotyledons, having become green in the light, to some extent carry on the work of photosynthesis (Fig. 236).

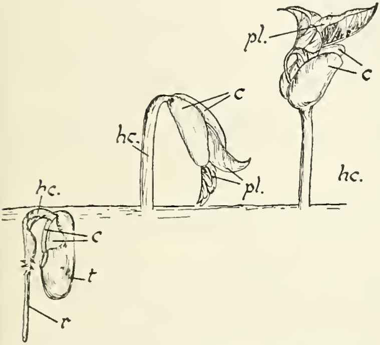


Fig. 235.—Stages in germination of French Bean, showing the elongation of the hypocotyl and the raising of the cotyledons. *c.*, cotyledon ; *hc.*, hypocotyl ; *pl.*, plumule ; *r.*, radicle.

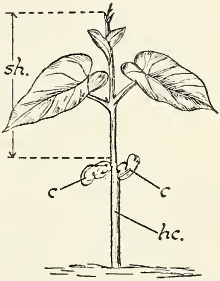


Fig. 236. — Germination of French Bean. *c.c.*, shrivelled cotyledons ; *hc.*, hypocotyl ; *sh.*, shoot developed from the plumule.

Dry and Wet Weights.

When a bean seedling grows in distilled water in the light its weight increases, partly because of the starch and sugar made in photosynthesis, but largely because of the water the roots have absorbed.

To determine the actual solid, or *dry weight*, the seedling should be carefully dried in an oven until all water is driven off.

To determine the gain in dry weight during germination comparison must then be made with the dry weight of an ungerminated seed, similarly heated.

Comparison may also be made with a seedling grown in the dark. In this case no photosynthesis has taken place. The *wet weight* of the seedling will, of course, be greater than that of the seed, because water has been absorbed. The dry weight of this seedling will, however, be less than the dry weight of the seed, because the reserves in the seed have been broken down during the growth of the seedling and carbon dioxide has been given off.

When a potato tuber sprouts in the dark, lying on the floor or on a shelf, it loses both dry weight and wet weight fairly rapidly, for it is giving off both carbon dioxide and water. Its branches may cover quite a wide area, but, none the less, tuber and branches weigh considerably less than the unsprouted potato.

Similar distinctions between dry weight and wet weight may be noted in foliage leaves.

By the end of a sunny day a leaf has given off a good deal of water, but it has made a great deal of starch. Its dry weight is therefore considerable.

A similar leaf in the early morning may weigh as much actually, because it has not been transpiring during the night. But if it is dried and then weighed, its dry weight is found to be less than that of the leaf picked in the late afternoon, because its starch has been converted into sugar and has travelled away from the leaf during the night.

The Sunflower "Seed."

What florists sell as Sunflower "seeds" are, in reality, Sunflower "fruits." They are the cypselas of the disk florets of the capitulum of the Sunflower. They can be seen, beautifully arranged, on the head of any Giant Sunflower, when the flowering-time is over.

The brittle pericarp is often somewhat striped, white upon brown. The scar at its pointed end marks its attachment to the receptacle. Another small scar in the notch at the farther end is the point where petals and style have withered away (Fig. 237, A).

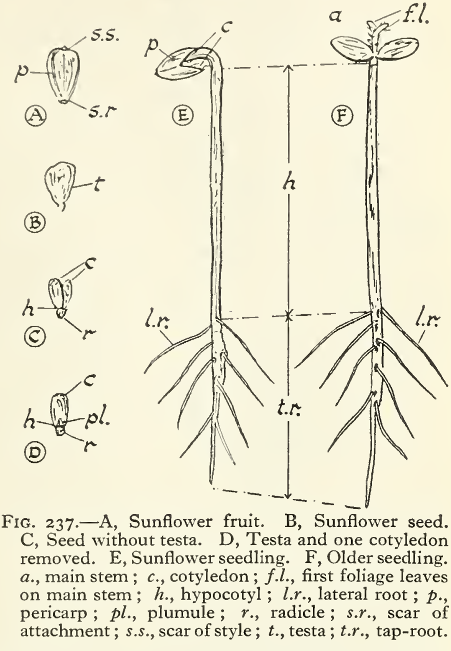


Fig. 237.—A, Sunflower fruit. B, Sunflower seed. C, Seed without testa. D, Testa and one cotyledon removed. E, Sunflower seedling. F, Older seedling. *a.*, main stem; *c.*, cotyledon; *f.l.*, first foliage leaves on main stem; *h.*, hypocotyl; *l.r.*, lateral root; *p.*, pericarp; *pl.*, plumule; *r.*, radicle; *s.r.*, scar of attachment; *s.s.*, scar of style; *t.*, testa; *t.r.*, tap-root.

There is so much air between pericarp and seed that the fruits always rise to the top of the water when they are being soaked.

The seed itself is covered with a testa so delicate that neither hilum nor micropyle can be seen, even with a hand lens. When the testa is removed and pressure released, the two vertical cotyledons spring apart and disclose the minute plumule which lies between them. The radicle is peg-like and points downwards (Fig. 237, C).

In this case, as in beans, the cotyledons store the food required in germination. It is, however, in the form of oil. If broken cotyledons are heated on white paper in a porcelain basin an oily smear spreads along the paper. On the addition of a drop of osmic acid a black stain confirms the presence of oil.

The germination of the Sunflower is epigeal, like that of the Kidney Bean. Both testa and pericarp protect the cotyledons when the elongation of the hypocotyl pushes them up through the soil. Several days pass before the cotyledons expand and the coats are thrown off (Fig. 237, E, F).

It is interesting to examine as many seeds as possible and note their differences. In the Sycamore, for instance, the cotyledons are very long and are tightly coiled. As they have always been within the dark fruit, shielded from the light, it is a surprise to find that they are green. The cotyledons of the Scotch Fir show this same unusual characteristic.

The seed of the Ash differs from all the foregoing in that the embryo does not fill up all the space within the testa.

The Ash Seed.

In a soaked Ash samara the brown seed is found lying attached by its long, curved funicle to a placenta at the upper end of the fruit. To see the embryo, the solid part of the seed must be sliced carefully with a sharp scalpel. An almost indistinguishable plumule lies between the two delicate cotyledons, and the apex of the peg-like root is directed away from the fruit stalk (Fig. 219, B^1).

Such delicate cotyledons cannot hold any food reserve. In this case the seedling's needs are provided by the *endosperm*, the tissue in which the embryo lies. In the Ash the endosperm is very largely cellulose, as it is in the Date. The test for cellulose is more easily carried out in the Date than in the Ash, because it is so much bigger. When the broken Date " stone " is treated first with iodine, then with concentrated sulphuric acid, a blue colour appears.

Cotton-wool is pure cellulose. It is a mass of the long hairs that grow from the testas of the Cotton seeds. It is easier to see the cellulose reaction in this than in either Date or Ash endosperm. If, after treatment, the hairs are mounted and examined under the microscope, it is seen that the walls swell in addition to turning blue.

The Castor Oil.

In the endosperm of the Castor Oil seed reserve food is stored as oil. This is readily proved by the osmic acid reaction (p. 397). The cotyledons are unusually filmy and are in close connection with the endosperm. The caruncle, or partial aril, possibly aids in absorption of water (Fig. 225).

All the seeds hitherto described have an embryo with two cotyledons. There is, however, a very large class of plants whose embryos have one cotyledon only.

Indian Corn.

The large size of Indian Corn (Zea Mais) as compared with the seeds of most cereals, makes it the best to choose for examination.

The grain is the whole fruit, a caryopsis, in which the fruit coat and seed coat grow together so closely as to be inseparable.

On one side of the flattish grain there is a pale area which indicates the position of the embryo (Fig. 238, A). The coat of a soaked grain is easily removed, and the embryo can then be taken out whole. Its removal leaves a hollow in the main mass, which is endosperm. When this tissue is tested the great bulk of it is seen to contain starch, but the nitric-acid test (p. 387) demonstrates the presence of protein in a layer just within the coat. It is this layer, too, that is particularly rich in vitamins (p. 200). This is so in all cereals and explains why highly refined flour makes less nourishing bread than does the coarser brown.

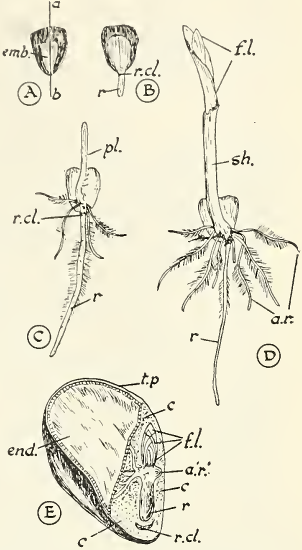


FIG. 238.—Zea Mais (Indian Corn). A, Fruit (caryopsis). B, The same germinating. C, D, Later stages of germination. E, Fruit sectioned in the plane *ab*, to show the embryo. *a.r.*, adventitious roots; $a^1.r^1.$, adventitious root developing; *c.*, cotyledon; *emb.*, position of the embryo; *end.*, endosperm; *f.l.*, foliage leaves (plumule); *pl.*, plumule; *r.*, main root; *r.cl.*, root collar; *sh.*, sheath enclosing foliage leaves.

One part of the embryo is somewhat shield-shaped and is, for this reason, called the *scutellum*. This is the one cotyledon (Fig. 238, E). The remaining smaller part is rather elongated

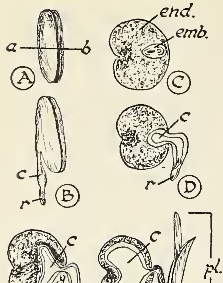


FIG. 239.—The Date (diagrammatic). A, The seed. B, Early stage in germination. C, The seed in section, cut in the plane *ab*. D, Section of B. E, F, Later stages in germination. Only part of F is drawn in section. The figures show the increase in size in the absorbing part of the cotyledon. *c.*, cotyledon; *emb.*, embryo; *end.*, endosperm; *pl.*, plumule; *pl*^{1}., plumule bursting through the ensheathing cotyledon; *r.*, root; *r.c.*, root-cap.

and cylindrical. The upper half of it is the plumule, and the lower the radicle.

To understand the relation of embryo to endosperm the whole grain must be cut in halves in a plane passing through the axis of the embryo. For this it is well to choose a grain that is symmetrical. This cut gives a median section of the embyro; plumule, radicle, and cotyledon are all exactly halved. In addition it is a great help to have a stained, mounted section which can be examined with a hand lens.

In this view the embryo lies to one side of the endosperm. The outermost layer of the scutellum is made up of cells whose special work it is to secrete enzymes as soon as germination begins. In the mounted section this layer appears as a row of cells, in close contact with the endosperm. It liberates certain enzymes that break down the cell-walls of the endosperm tissue; others follow and act upon the stored starch, turning it into sugar. The sugar passes along the cotyledon to the radicle and plumule. The former points downwards in the grain. The leaves of the latter are enclosed in a sheath which splits as the plumule elongates. When the radicle emerges it also ruptures a sheath of special tissue, which remains attached to the upper part of the root as a collar, or *coleorhiza* (Fig. 238, E).

The primary root has but a brief

existence. Before it dies off, adventitious roots grow from the base of the stem (Fig. 238, D). These form the fibrous root characteristic of all grasses (p. 261).

The Date Seed.

In the Date seed the one cotyledon is circular and sheathing. It absorbs the endosperm store, which is, in this case, cellulose. As it absorbs it elongates, pushing the radicle and plumule down into the ground. Its upper part splits, and here the spike of the plumule emerges. In this case the cotyledon is much more active than that of the Maize. It not only grows downwards, but it expands greatly at its tip, which is still within the seed absorbing the reserve food (Fig. 239).

The Onion Seed.

The one cotyledon of the Onion is rather like that of the Date, but it is epigeal, growing upwards as well as downwards. As its tip is still inside the seed it comes up through the soil sharply bent. When the bend straightens, the remainder of the seed is usually dragged upwards, with the tip of the cotyledon still within it, still absorbing the reserve food of the endosperm (Fig. 240).

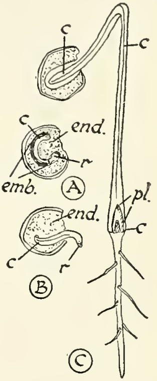


FIG. 240.—Onion (diagrammatic). A, Seed in section, B, C, Stages in germination. *c.*, cotyledon; *emb.*, embryo; *end.*, endosperm; *pl.*, plumule; *r.*, radicle.

The Work of Cotyledons.

These few examples of seed-structure serve to show the very special work of the cotyledons; it is their business to provide food for the growing root and shoot, either directly or indirectly. Directly either by containing some food store in their own tissues or by actively manufacturing food; indirectly by making available some additional supply.

In the bean the hypogeal cotyledons store the food that, as a result of enzyme action, is absorbed by radicle and plumule.

In the Sunflower this is the case also, but the epigeal cotyledons turn green in the light and carry on the work of photosynthesis.

In Maize, Onion, and Date the cotyledon acts indirectly in this matter of the food supply, absorbing it from the endosperm and passing it on.

In the Castor Oil the work of the cotyledons is indirect in the early stages of germination, when they absorb the food from the endosperm against which they lie so closely. Later they appear above the ground as the first green leaves of the plant and, by carrying on the work of photosynthesis, contribute directly to the seedling's food supply.

CHAPTER XXVII

A SYNOPSIS OF SOME OF THE MORE COMMON FAMILIES OF FLOWERING PLANTS

FLOWERING Plants whose seeds are within an enclosed fruit are known as *Angiosperms*. They are subdivided into the two large classes of *Dicotyledons* and *Monocotyledons*. As these names imply, the seeds (except in rare cases) in the one class have an embryo with two cotyledons and, in the other, an embryo with one cotyledon only.

Monocotyledons and Dicotyledons.

These differences in the seed are associated with differences in every part of the plant.

In almost every case the primary root in Monocotyledons is replaced by adventitious roots. The internal structure of roots, as seen under the microscope, is on a different plan in Monocotyledons and Dicotyledons.

The internal structure of the stem is also different in the two classes. A cambium is only present in very few Monocotyledons, whereas secondary growth, resulting from cambial activity, is general in Dicotyledons.

The leaves of Monocotyledons are simple and rarely have stipules. The veins of the leaf in nearly every case run parallel.

In Dicotyledons the leaves may be simple or compound; they may be stipulate or ex-stipulate; but in almost every dicotyledonous leaf the veins branch from a midrib and the branches themselves branch again and again, so that a perfect network of veins is formed.

In the flowers of Monocotyledons there is no distinction of the perianth into calyx and corolla. There are generally two whorls of leaves, but these are almost identical in form and function.

The differentiation of the perianth into calyx and corolla is not invariable in Dicotyledons, but it does occur in the great majority of cases. Where one set of leaves is present, as in the Clematis, for instance, it is the calyx, with the sepals in one whorl.

Again the number of leaves in the floral whorls is different in the two classes. It is usual for the floral whorls of Monocotyledons to be in threes or multiples of three. In Dicotyledons the numbers generally run in fours or fives.

MONOCOTYLEDONS

(1) LILIACEÆ

There is great variety of vegetative structure in this family.

The perennating organ may be a *bulb*, as in the Tulip and Hyacinth and Tiger Lily. It is a *rhizome* in the Lily of the Valley and Solomon's Seal. It is a *corm* in the Autumn Crocus.

Smilax has stipules in the form of tendrils. Dwarf shoots occur in Asparagus and Butcher's Broom.

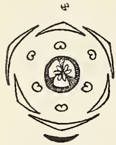


FIG. 241.—Floral diagram of Liliaceæ.

TULIP

Perianth : Six leaves in two alternating whorls, free, inferior.

Andrœcium : Six stamens, in two whorls, free, either hypogynous or growing on the perianth leaves.

Pistil : Three carpels, joined, superior.
Stigma : Three-cleft.
Style : Absent.
Ovary : Three-chambered.
Placentation : Axile.
Fruit : A capsule.

Floral Formulæ : KC 3 + 3. A3 + 3. $G\underline{(3)}$.

In the Hyacinth the stamens grow on the perianth leaves (epiphyllous).

In the Lily of the Valley the perianth leaves are joined.

In some cases the fruit is a berry, e.g. Butcher's Broom, Lily of the Valley, Solomon's Seal.

References : Pp. 335, 343, 361, 366 (Fig. 241).

(2) AMARYLLIDACEÆ

The plants are like those of Liliaceæ in habit.

The flowers resemble those of Liliaceæ in most respects, but the ovary is inferior.

A *corona* develops from the perianth in all the Narcissus group. It is short in the Pheasant's Eye and long in the Daffodil.

Floral Formula : KC (3 + 3). A3 + 3. $G\overline{(3)}$.

References : Pp. 342, 343, 352.

DICOTYLEDONS

Grade A

Flowers in which the perianth is either lacking or extremely simple. Flowers frequently unisexual.

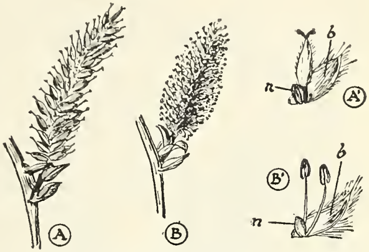


Fig. 242.—The Sallow Willow. A, Female inflorescence (catkin). B, Male inflorescence (catkin); A¹, Female flower. B¹, Male flower. *b.*, bract; *n.*, honey gland.

(1) Salicaceæ

Trees with simple, stipulate leaves.

Diœcious, i.e. male and female flowers on different trees.

Inflorescence, a catkin.

Willow

Perianth : Represented by a nectary.

Male Flower : Two-several stamens.

Female Flower : Two carpels, joined.

Insect-pollinated (Fig. 242).

Poplar

Perianth : Cup-like.

Male Flower : Numerous stamens.

Female Flower : Two carpels (generally).

Wind-pollinated.

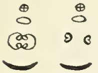


Fig. 243.—Floral diagrams of flowers of the Sallow Willow.

The placentation in this family is parietal. The fruit is a capsule opening by two valves. The seeds are wind-dispersed, each having an aril of hairs at its base.

References : Pp. 341, 342, 348 (Fig. 243).

(2) Betulaceæ

Trees, with simple, stipulate leaves.

Monœcious, i.e. male and female flowers on the same tree.

Hazel (Fig. 244)

Male Catkins : Long and pendulous.

Male Flowers : No perianth.

Stamens, four.

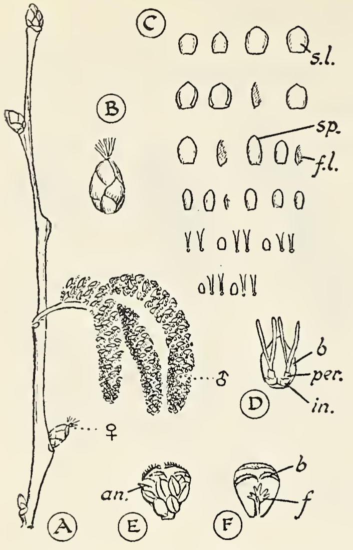


FIG. 244.—Hazel. A, Twig with male (♂) and female (♀) flowers. B, Bud containing ♀ flowers. C, Dissection of bud containing ♀ flowers. D, Two ♀ flowers with bract. E, ♂ flower. F, ♂ flower with anthers removed. *an.*, anther, *b.*, bract; *f.*, filament; *f.l.*, foliage leaf; *in.*, involucre; *per.*, perianth; *s.l.*, scale-leaf; *sp.*, stipule.

Female Flowers: Very small; enclosed in leaf-buds.

Perianth: Small, superior.

Pistil: Two carpels.

In spring the red stigmas of the female flowers protrude from the tips of flower buds.

Wind-pollinated.

Fruit: A nut, surrounded by the persistent bracts of the female flower (Fig. 197).

References: Pp. 353, 376.

(3) ULMACEÆ

Trees, with simple, stipulate leaves.

ELM

Flowers: Bi-sexual.

Perianth: Five-lobed.

Stamens: Five.

Pistil: Two carpels joined.

Wind-pollinated.

Fruit: A samara.

References: Pp. 342, 376.

GRADE B

Flowers generally bisexual with *free petals.* Pollinated by insects.

(a) *Hypogynous Flowers*

(1) RANUNCULACEÆ

Herbs (except Clematis).

Poisonous or bitter juices in most plants.

Leaves usually sheathing at the base.

Solitary or cymose inflorescence.

All parts of the flower free (except Love-in-a-Mist, where the carpels are joined and the fruit is a capsule).

Fruit : Achenes or follicles.

Achenes : Buttercup Anemone, Clematis.

Follicles : Peony, Globe Flower, Christmas Rose, Columbine, Larkspur, Monkshood.

One whorl to the perianth and that a *petaloid calyx:* Marsh Marigold, Anemone, Clematis.

Petaloid calyx and *outer stamens modified to form nectaries* : Globe Flower, Hellebore, Christmas Rose, Love-in-a-Mist.

Floral Formula :

Buttercup $K5\ C5\ A\infty\ G\underline{\infty}$.
Lesser Celandine $K3\ C8\ A\infty\ G\underline{\infty}$.
Clematis $K4\ C0\ A\infty\ G\underline{\infty}$.
Delphinium $K5\ C5\text{–}8\ A\infty\ G\underline{3}$.

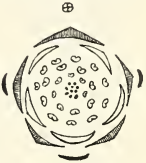


FIG. 245.—Floral diagram of Buttercup.

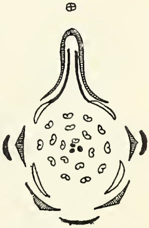


FIG. 246.—Floral diagram of Delphinium.

In Buttercup and Lesser Celandine there is a honey gland at the base of each petal (p. 362). The open flowers are accessible to all insects. The immature stamens bend over the carpels ; later they become first erect, then bend outwards. The anthers open extrorsely and the pollen falls into the trough of the petal or on to the back of insects, which thus receive pollen ventrally and dorsally. The youngest stamens frequently remain curved over the carpels and bring about self-pollination by dropping pollen on to the stigmas.

References : Pp. 346, 349, 361, 378 (Figs. 245 and 246).

(2) CARYOPHYLLACEÆ

Herbs. Leaves in pairs. Swollen nodes. Cymose Inflorescence.

Sepals free, and three carpels (Stitchwort), or :

Sepals joined, and generally five carpels (Pink, Campion).

Placentation : Free central.

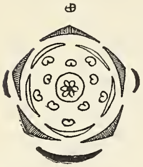


FIG. 247.—Floral diagram of Stitchwort.

When the flower is looked at from above the five outer stamens appear *opposite* the petals, not alternating with them. They have apparently been mechanically pushed into this position during development.

Floral Formula :

Stitchwort $K5\ C5\ A5+5\ G(\underline{3})$.

Campion $K(5)\ C5\ A5+5\ G(\underline{5})$.

The Red Campion is diœcious. The female plant can generally be distinguished from the male ; it has thicker stems and larger leaves.

References : Pp. 336, 340, 354, 370 (Fig. 247).

(3) CRUCIFERÆ

Non-poisonous Herbs.

WALLFLOWER

Perianth : Calyx, four sepals in two whorls, free, inferior, two sepals are pouched at the base. *Corolla*, four petals, cruciform, free, inferior. Each petal has two parts, a limb and a claw.

Andrœcium : Six stamens, four long and two short (tetradynamous), free, hypogynous. Honey glands at the base of the two short stamens account for the bulging sepals.

Pistil : Two carpels, joined, superior.

Stigma : Two-lobed.

Style : Absent.

Ovary : Divided by a false septum.

Fruit : A siliqua (Fig. 215).

Floral Formula : $K2+2\ C4\ A6\ G(\underline{2})$.

Familiar Canadian Crucifers are Stinkweed (Frenchweed), Tumbling Mustard, Wormseed Mustard, Ball Mustard, and Shepherd's-purse.

References : Pp. 350, 356, 371, 385 (Fig. 248).

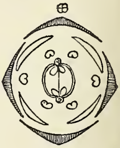


FIG. 248.—Floral diagram of Wallflower.

(4) VIOLACEÆ

Herbs.

VIOLET

Perianth : Calyx, five sepals, free, inferior, attached to the receptacle a little distance from the base. *Corolla*, five petals, free, inferior, irregular. The anterior petal is pouched.

Andrœcium : Five stamens, free, hypogynous. Filaments almost absent. Connectives extend beyond the anthers. Spurs which are nectaries project from the two anterior stamens and fit into the spur of the petal where the honey collects.

Pistil : Three carpels, joined superior.

Stigma : Globular.

Style : Not quite straight.

Ovary : One-chambered.

Placentation : Parietal.

Fruit : Capsule, opening by valves.

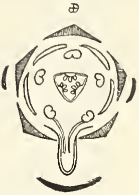


FIG. 249.—Floral diagram of Violaceæ.

Floral Formula :

$K5\ C5\ A5\ G(\underline{3})$.

Pollination : The shape of the flower conforms closely to the general outline of a bee's body (Fig. 250). The orange connectives against the purple petals make a strong colour contrast, intensified by the pale bases of the petals and the dark "honey guides." The sweet smell and plentiful honey add to the attraction of the flower.

Pollination in the Pansy is very interesting. The stigmatic surface is a little pit in the round stigma and is protected by a valvular flap.

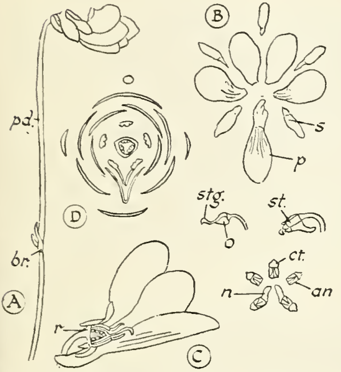


FIG. 250.—Violet. A, One flower. B, Dissection of flower. C, Longitudinal section. D, Floral diagram. *an.*, anther, *br.*, bracteole, *ct.*, connective; *n.*, nectary; *o.*, ovary; *p.*, petal; *pd.*, peduncle; *s.*, sepal; *st.*, stamen; *stg.*, stigma.

The closely fitting anthers open introrsely and the pollen falls through the cylinder they make into a depression of the anterior petal near the entrance to its spur. The proboscis of the bee rubs against this when it is inserted into the spur to get honey. When the bee withdraws its proboscis it pushes against the stigmatic valve and closes it, so that there is no self-pollination. Entering another Pansy, it pushes against the valve in the opposite direction and, opening it, deposits pollen in the stigmatic pit. In this way cross-pollination is brought about.

References : Pp. 350, 366, 384.

(b) *Perigynous Flowers*

(1) ROSACEÆ

Plants of very different habit.

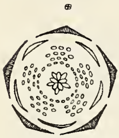


FIG. 251.—Floral diagram of Rose.

Flowers perigynous and all the parts free (Apple has an inferior and syncarpous pistil).

ROSE

Perianth : *Calyx*, five sepals, free, perigynous. *Corolla*, five petals, free, perigynous.

Andrœcium : Numerous stamens in alternating whorls, free, perigynous.

Pistil : Numerous carpels, free.

Fruit : Collection of achenes.

Floral Formula : $K5\ C5\ A\infty\ G\infty$.

Other common members of this family are Saskatoon, Strawberry, Cinquefoil, Avens, Cherry, and Spiræa.

References : Pp. 363, 369, 373, 375, 383 (Fig. 251).

(2) LEGUMINOSÆ

Trees, shrubs, herbs.

The second largest family of Flowering Plants, only exceeded in numbers by the Compositæ.

Occurs in all parts of the world and contains many plants of economic importance.

Seeds rich in starch and protein : Peas, Beans.

Fodder plants : Clover, Alfalfa (Lucerne).

Medicinal : Senna.

Some members yield timber, resin, and dyes.

Tubercles on roots of many of the plants help in the formation of nitrates (Fig. 231).

The outstanding characteristics of British members of the family are:

The papilionaceous corolla.
Stamens joined by their filaments.
One carpel in the pistil.
Fruit a pod (legume).

Sweet Pea

Perianth : Calyx, five sepals, joined, perigynous. *Corolla*, five petals, free (two slightly joined), perigynous; one standard, two wings, two petals in the keel.

Andrœcium : Ten stamens, nine joined, one free (diadelphous), perigynous.

Pistil : One carpel.
Stigma : Blunt.
Style : Curved.
Ovary : One-chambered.
Placentation : Axile.
Fruit : Legume or Pod.

Floral Formula : $K(5)\ C5\ A(9)+1\ G1$.

Pollination : In the flowers of this Family that have honey, this is secreted by the bases of the filaments on their inner side and collects round the ovary. It is accessible to an insect with a long proboscis, and pollination depends chiefly upon bees.

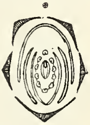


Fig. 252.—Floral diagram of Sweet Pea.

The petals serve different functions: the stamens are protected within the keel; the standard is conspicuous and attracts insects; the wings serve as an alighting ground.

The petals are mechanically united by a system of interlocking bumps and depressions on standard, wings, and keel.

The general principle of pollination is that the heavy insect, astride the keel, depresses this, causing an outpushing of stamens and stigma, so that the insect's abdomen, in the case of a young flower, receives the pollen, while in an older one it dusts pollen on to the stigma (Fig. 253). Self-pollination probably takes place quite as frequently as cross-pollination.

In Clover and Laburnum, at the conclusion of an insect's visit the stamens and style return to their position within the keel. These flowers may be visited several times.

The untidy appearance of the flowers of the Broom is due to the fact that the pressure of the insect's body causes an explosion within the flower, and a cloud of pollen is expelled upwards. The flower produces no honey and is not visite a second time (Fig. 254).

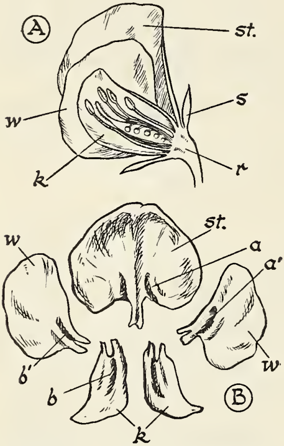


FIG. 253.—A, Longitudinal section of Sweet Pea. Three of the nine joined stamens are shown; the tenth stamen is free. B, The petals with grooves and ridges for interlocking. *k.*, keel; *r.*, receptacle; *s.*, sepal; *st.* standard; *w.*, wing; *a.* and a^1. and *b.* and b^1. interlock.

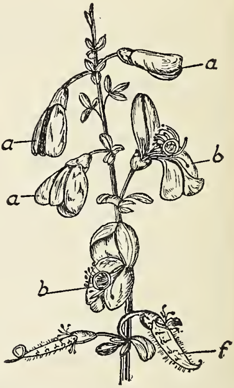


FIG. 254.—Broom, showing the small foliage leaves of a xerophytic plant and the collapse of the flowers after an insect's visit. *a.*, unvisited flowers; *b.*, visited flowers; *f.*, a pod, with dead stamens and persistent calyx at its base.

In Bird's Foot Trefoil there is a narrow opening at th tip of the keel which is full of shed pollen. On the depressio of the keel the filaments act as a piston and push a trail of polle out through the hole, bringing it into contact with the ventra surface of the bee.

In the Pea and Bean short hairs on the style sweep the pollen out of the keel (Fig. 253).

References : Pp. 363, 385.

GRADE C

Flowers with *joined* petals (gamopetalæ).

(a) *Hypogynous Flowers*

(1) PRIMULACEÆ

Herbs.

In the flower the epipetalous stamens are *opposite* the lobes of the corolla.

PRIMROSE

Perianth : *Calyx*, five sepals, joined, inferior. *Corolla*, five petals, joined, inferior. Limb and claw.

Andrœcium : Five stamens, free, epipetalous. Opposite the petals.

Pistil : Five carpels, joined, superior.
Stigma : A knob.
Style : Slender.
Ovary : One-chambered.
Placentation : Free central.
Fruit : A capsule opening by teeth.

Floral Formula : $K(5)\ C(5)\ A5\ G(\underline{5})$.

References : Pp. 340, 348, 350, 358, 360, 371 (Fig. 255).

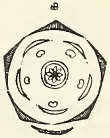


FIG. 255.—Floral diagram of Primrose.

(2) LABIATÆ

Mostly herbs. Square stems. Leaves in alternate pairs (opposite decussate).

Flowers irregular, two-lipped. The posterior stamen is missing. Fruit a schizocarp of four nutlets.

WHITE DEAD NETTLE

Perianth : *Calyx*, five sepals, joined, inferior, irregular. *Corolla*, five petals, joined, inferior. Bilabiate. Two petals in the upper lip, three in the lower.

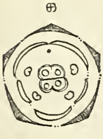


FIG. 256.—Floral diagram of Dead Nettle.

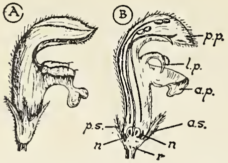


FIG. 257.—White Dead Nettle. A, The whole flower. B, Longitudinal section of a similar flower. *a.p.*, half anterior petal; *a.s.*, anterior sepal; *l.p.*, lateral petal; *n.*, nectary; *p.p.*, posterior petal; *p.s.*, half posterior sepal. *r.*, receptacle.

Andrœcium : Four stamens, free, epipetalous. Two long and two short (didynamous).

Pistil : Two carpels, joined, superior.

Stigma : Forked.

Style : Long and slender.

Ovary : Dividing into four.

Floral Formula: $K(5)\,C(5)\,A4\,G\underline{(2)}$ (Fig. 256).

Pollination : The flowers are protandrous. When the insect enters for honey its back receives the pollen. When it enters a flower in which the anthers are withered the forked stigmas come in contact with its back and pick up pollen (Fig. 257).

In the Sage there are only two stamens, whose pollen sacs are separated by an extended connective. One of the sacs contains no pollen. On entering the flower the bee comes in contact with these barren sacs in such a way that the connective swings round. The upper sacs, containing pollen, then strike downwards and leave pollen upon the back of the bee. In older flowers the stigma curves over so as to come into contact with the bee's back (Fig. 258).

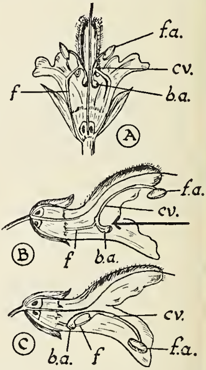


FIG. 258.—Sage. A, Flower with anterior sepals and petal removed. B, Vertical (longitudinal) section, showing the normal position of the stamen. The arrow marks the insect's direction on entering. C, Shows the swinging over of the fertile anther (*f.a.*) as a result of the insect's pushing against the barren anther (*b.a.*) in the search for honey. *b.a.*, barren anther; *cv.*, extended connective; *f.*, filament; *f.a.*, fertile anther.

Familiar Canadian Labiates include Woundwort (Stachys), Wild Mint (Mentha), Wild Bergamot (Monarda), Giant Hyssop (Agastache), and Blue Skullcap (Scutellaria).

References : Pp. 359, 373.

(3) SCROPHULARIACEÆ

Mostly herbs.

Flowers irregular. The posterior stamen generally missing.

Fruit a capsule.

In Penstemon and Figwort a barren stamen (staminode) is present posteriorly.

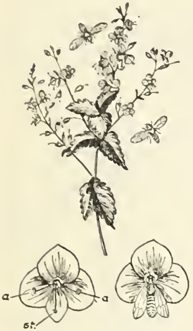


FIG. 259.—Pollination of Veronica by Hover-flies. The stamens in this flower are hinged. The fly, alighting on the flower, supports itself by the stamens in such a way that they are drawn under its body. The pollen thus received on the fly's under surface is later deposited on the mature stigma of another flower. *a.a.*, anthers of the two hinged stamens; *st.*, the stigma.

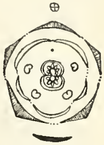


FIG. 260.—Floral diagram of Snapdragon.

In Mullein all five stamens are present and the flower is nearly symmetrical.

In Veronica (Speedwell) the two posterior petals have united to form one. The alternation of the sepals is maintained by a reduction of their number to four. Only the two anterior stamens are present (Fig. 259).

Floral Formula :

K(5) C(5) A4 G$(\underline{2})$.

References : Pp. 344, 356, 360 (Figs. 260, 261).

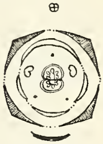


FIG. 261.—Floral diagram of Speedwell.

(b) *Epigynous Flowers*

COMPOSITÆ

Herbs or shrubs.

Inflorescence a capitulum. Involucre of bracts.

Anthers syngenesious.

Fruit a cypsela.

Ligulate Flowers only : Dandelion, Hawkweed, Sow-thistle, Goat Chicory (Prairie Dandelion).

Perianth : Calyx, pappus, superior. *Corolla*, five petals, joined to form a strap ending in five teeth, and forming a short tube basally, superior.

Andrœcium : Five stamens, syngenesious, epipetalous.

Pistil : Two carpels, joined, inferior.

Floral Formula : K pappus C(5) A(5) G$\overline{(2)}$.

Tubular Flowers only: Common Groundsel, Thistles, Burdock, Everlasting (Antennaria).

Perianth: Calyx, pappus, superior. *Corolla*, five petals, joined to form a tube, superior.

Andrœcium: Five stamens, syngenesious, epipetalous.

Pistil: Two carpels, joined, inferior.

Floral Formula: K pappus $C(5)\ A(5)\ G\overline{(2)}$ (Fig. 262).

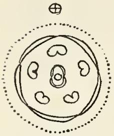


Fig. 262.—Floral diagram of a tubular flower of the Compositae.

In the Cornflower the florets are tubular, but those of the outer row are irregular, much enlarged, and barren, and serve for attraction (Fig. 263).

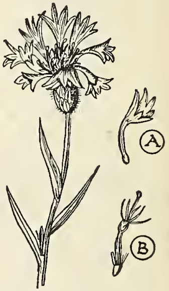


Fig. 263.—Cornflower, showing the outer tubular flowers modified for attraction. A, Barren (neuter) flower. B, Flower with stamens and pistil.

Outer florets, ligulate; inner, tubular: Daisy, Aster, Yarrow, Gum-plant, Sunflower, Golden-rod.

Ligulate or Ray Florets:

Perianth: Calyx, None. *Corolla*, three petals, joined to form a strap with short basal tube, superior.

Andrœcium: None.

Pistil: Two carpels, joined, inferior.

Floral Formula:

$$K0\ C(3)\ A0\ G\overline{(2)}.$$

Tubular or Disk Florets:

Perianth: Calyx, none (or two to five small scales). *Corolla*, five petals, joined, superior.

Andrœcium: Five stamens, syngenesious, epipetalous.

Pistil: Two carpels, joined, inferior.

Floral Formula: $K0\ C(5)\ A(5)\ G\overline{(2)}$.

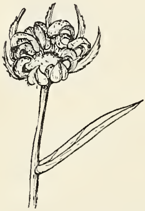


Fig. 264.—Head of Marigold fruits. The disk flowers have fallen.

In the Coltsfoot and Marigold the disk florets are male. They contain a pistil, but there is no stigmatic surface. The style merely acts as a piston to sweep pollen out of the anther-tube. It is only in these flowers that honey is produced. The ray florets are female. This explains the occurrence of fruits on the rim of the receptacle only (Fig. 264).

In the Sunflower the ray florets have neither stamens nor carpels, i.e. they are neuter.

References : Pp. 351, 359, 377, 383, 384.

SECTION V

THE SOIL—BACTERIA—PARASITES AND SAPROPHYTES—DISTINCTION BETWEEN PLANTS AND ANIMALS—INTERRELATION OF PLANTS AND ANIMALS

CHAPTER XXVIII

THE SOIL

In studying soil the essential factors of the problem must be realised at the outset. It is quite possible to tabulate results neatly, and yet miss the significance of the experiments that have been carried out.

At first sight the soil may appear rather a dull subject for investigation. As it is, however, from soil and air that plants directly, and animals indirectly, derive their food, it is important to find out not only what food a plant gets from the soil, but also how it obtains it.

It has already been seen that the root-hairs of a plant absorb soluble substances from the soil by osmosis (p. 246). A study of *the chemistry of soil* will make the nature of the dissolved substances clear.

It has also been seen that the root can only absorb dilute solutions (p. 251). It follows from this that a plant must take in a large quantity of water if it is to obtain any appreciable nourishment. The water content of the soil is thus extremely important, and a *physical study of soil* must determine in what condition the water is held so that it may be readily absorbed.

The problem is thus two-fold. It is well to begin with a preliminary analysis of a sample of soil from any convenient source.

Preliminary Analysis of Soil. Some of this should be spread out on a piece of paper and examined. It is found to contain bits of twigs and leaves and other plant remains, in different stages of decomposition. Some are large enough to be picked out; others cannot be separated in this way. This decaying organic matter is the *humus* of the soil.

In addition there are grains of various sizes. Some are easily seen with the naked eye. Others grade down to a mere powder. It is important to remember that the physical properties of soil depend largely upon the size of the particles.

If the rest of the soil sample is put into a beaker and is shaken up with water, the humus floats to the top and is easily removed. The remainder can be roughly analysed by adding water, stirring, and decanting at least three times. Each time the beaker is allowed to stand for one minute and the liquid is then poured off into a large vessel. In this way all the smaller and lighter particles will have been transferred to the large vessel, which is then set aside.

The sediment that remains in the beaker is dried, and sifted through a piece of wire gauze. In this way its constituents are roughly separated, for the larger pieces of gravel remain on the gauze, while coarse sand sifts through.

At the end of half an hour it is possible to decant off the liquid of the large vessel from a sediment of fine sand. The decanted liquid must then stand for a long time, probably for several days. When it finally settles there will be a sediment of extremely fine particles of a clayey nature.

This series of experiments has proved that the solid part of the soil is made up of different constituents: these are humus, gravel, coarse sand, fine sand, clay.

Of these five constituents the four last are quite insoluble in water. They cannot, therefore, supply food to growing plants. They are, as it were, the framework of the soil, and their importance to the plant depends largely, if not entirely, on the size of their particles, since it is this that determines the capacity of the soil for holding air and for retaining water.

The humus, too, is not immediately soluble, but as it is in a state of continual decomposition and change, it may, eventually, produce soluble substances for the plant's food.

The inorganic part of the soil, that is, all that has not been produced by the decay of living things, is formed from the breaking down of the rocks of which the earth's crust is made.

The Origin of Soils.

The face of a cliff or quarry shows a series of layers which roughly correspond to those named in the accompanying table. This table should be read from the bottom upwards.

SOIL	Dark-coloured layer of fine earth containing roots both of dead and living plants. No stones.
SUBSOIL	Light-coloured layer without roots of plants. Material practically all loose.
	More loose material and fewer stones.
	Loose disintegrated rocks and smaller stones.
	Loose pieces of rocks and stones.
SOLID	Fractured rock.
ROCK	Solid rock, usually showing layers or strata.

The rocks that form the earth's crust are gradually being broken up by the action of weathering agents. The rain, as it falls, dissolves oxygen and carbon dioxide from the atmosphere; this absorption of carbon dioxide makes the water slightly acid, and thus it acts as a solvent, causing gradual disintegration of the rocks. Frost is another powerful weathering agent; when water that lies in the cracks of rocks freezes, it expands; this expansion exerts a force which splits the rock. Alternate heating and cooling of rocks with the consequent expansion and contraction also help to break them up, especially when they consist of different constituents with different rates of expansion. A continual wearing away of rocks results from these combined causes, and it comes about that in process of time there is a gradual transition from the solid rock to the subsoil.

Above the subsoil is a layer of a few inches of dark-coloured soil quite different in appearance from the subsoil below. The roots of plants confine themselves almost entirely to this layer, and the dark colour is due to decaying vegetable matter, or humus. This layer is the soil proper from which vegetable life draws its nourishment. Here the earthworms are continually at work aerating the soil by the excavation of their burrows and by bringing up to the surface fresh finely divided earth (p. 42). Here, too, the delicate roots of plants are boring their way between the particles and still further breaking up the soil. And here, too, the conditions are being constantly modified by the decay of old roots producing rich humus.

Soils that have been formed in the manner above described are termed *sedentary* soils ; in them the soils actually lie on the top of the rocks from which they have been produced.

It does not, however, always follow that the soil at the surface contains the same constituents as the rock on which it rests. Soils may be carried by rivers and by glaciers, and deposited far from the place in which they were formed.

As a river flows from the heights to the sea it carries with it a large amount of solid matter in suspension, more particularly when it is in spate. This is readily proved by collecting a jar of water from a quick-running stream. When it is left to stand a lot of sediment falls to the bottom of the jar. This sediment is usually fine-grained and feels clayey or sticky to the touch.

When the speed of the river is suddenly checked, as happens when it reaches the sea, a large amount of the material that it has carried down is deposited. The characteristic mud flats which occur at the mouths of rivers are formed in this way. In such areas the constituents of the mud may be entirely different from those of the rocks on which the mud now rests.

Again, a river often overflows its banks in time of flood and a thin layer of water spreads out over the plain. As this water soaks through the earth it leaves a sediment behind. Thus a soil gradually accumulates over the plain.

Soils that are formed in this way, far from their place of origin, are termed *sedimentary* or *alluvial* soils.

Composition of the Soil.

Although it is usual to speak of soils as " sandy " or " clayey," no soils consist entirely of any one substance. The name simply implies that the relative amount of the material which determines the name is in this case large, probably 60–80 per cent. Soils are all more or less mixtures of various components. A mixture of sand and clay in which neither predominates is described as *loam*. A certain amount of chalk is a constituent of a great many soils. In some cases the chalk predominates and a *chalky soil* results. *Leaf-mould* and *peat* are both forms of humus. If either predominates it gives its name to the soil produced.

As the importance of the inorganic part of the soil depends largely upon its power of retaining water, a comparison of soils from this point of view must be made.

It follows from what has been said already, that any soil that is rich in food substances must be able to retain a large amount of water. Simple tests of the relative water-containing capacity of certain soils may be carried out with samples of clay, sand, and loam.

Water Content of Soil.

The soils should first be dried, either by spreading them out in the sun, or in front of a fire. If a water-oven is available they can be dried in this at 100° C.

Portions of the dried soils are powdered as finely as possible in a mortar, and put into separate funnels plugged with cotton-wool. The funnels are then placed over three measuring cylinders. Using the rose of a small watering can, an equal quantity of water is poured over each soil sample. The use of the rose ensures an even distribution of the water, resembling the falling of rain. In this way it is possible to compare the rate at which the water goes through in each case and also the amount of water that is retained by the soil.

As a result of this experiment it is seen that sand retains very little water, loam retains more, while the clay keeps almost the whole of it.

This illustrates what happens at the surface of the soil when it rains.

But soils are not entirely dependent for their supply of water on the falling rain. They can be watered from below as well as from above. This is of immense importance in times of drought. Were it otherwise most plants would die in dry weather from lack of moisture, since their roots do not penetrate more than a few inches below the surface of the soil.

If in the experiment just described more and more water were poured through the funnels there would come a time when the water in the cylinders below would reach the level of the soil in the funnels. A condition somewhat similar to this does occur some distance below the soil surface. When water which is trickling through the soil can get no further, because it is prevented by some impervious stratum such as rock or clay, it collects at this level and the earth becomes saturated with it. The level at which the water stands is termed the *water-table*. It is of the utmost importance to plant life, since water is able to rise from the water-table to moisten the soil above it. *In Western Canada the water-table seldom occurs.*

That water can rise in this way is proved by the following simple experiment. Over one end of each of three cylindrical lamp chimneys a piece of muslin is tied, and the chimneys are then filled respectively with sand, loam, and clay. The chimneys stand on end in a trough into which a small quantity of water is then poured.

Gradually the water creeps up through the soils. At first it ascends most rapidly through the sand ; after a time the water in the cylinder which contains the clay reaches and passes the level of that in the sand. Eventually the water rises farthest in the clay, least in the sand, and to some point midway between the two, in the loam.

It follows, then, that the rise of water from the water-table is determined by the size of the particles of which the soil is composed, and is in no way dependent upon its chemical composition. Water will pass in this way in any direction in the soil, from a wet part to a drier one.

The rise of water in the soil is due to the force of *capillary attraction*. Capillarity may be very simply demonstrated in the laboratory. A piece of glass tubing, heated in the middle and then pulled out, gives a length of very fine tubing, whose bore is different at different parts of its length. It is then cut up into short pieces which are fixed upright in a little water coloured with red ink.

The water begins to rise in the tubes ; it rises farthest in the one of smallest bore ; it does not rise at all in those in which the bore is too large. On examining the surface o the liquid in the tubes it is seen to be concave, and not flat and the smaller the bore of the tube the greater is the concavity of the surface of the liquid. This is explained by saying that the inner surfaces of the tubes exert a pull on th water and that the strength of this pull is greater the narrowe the tube. The force that holds the water up is called *surface tension* and the tubes are termed *capillary tubes*.

As the particles of which the soil is composed are of different shapes and sizes they do not fit tightly together. The spaces between the particles form a series of branching capillary tubes. The soil particles act in the same way as the inner surfaces of the tubes in the above experiment and the water is held up by surface tension. It follows that the smaller the particles of soil the smaller will be the capillary tubes, and, therefore, the greater the rise of water.

The films of water that surround the particles are elastic, and the drawing of water from one part sets up a flow in that direction, until the films are again of equal thickness. This means that the thin film of water round any particle will draw water from a thicker film with which it is in contact.

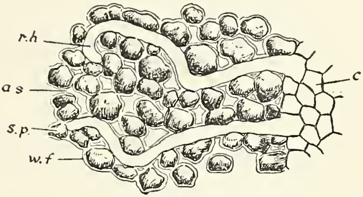


FIG. 265.—Root-hairs in the soil. *a.s.*, air spaces; *c.*, cells of root; *r.h.*, root-hairs; *s.p.*, soil particles; *w.f.*, water films.

The action starts when the particles that are in contact with the water-table become coated with a thin film of water. A part of this water is then taken from them by the neighbouring particles whose water films are thinner still, and so the water slowly percolates, always from the wetter to the drier region. The water film which connects particle with particle is unbroken, but there are minute spaces between the particles which are full of air.

It is from the thin films of water that surround the soil particles that the delicate root-hairs of the plant absorb moisture (Fig. 265). If water stands in the spaces between the particles the hairs do not absorb normally.

In time of drought the water films may become so thin that the plant could not take more moisture without breaking the film. Because of the surface tension of the film it cannot do this, and it follows, therefore, that a root is unable to absorb water although the soil is not absolutely dry. Such unavailable water is termed "*hygroscopic water*."

Evaporation of Water at the Surface of the Soil.

Water, then, rises through the soil by capillary attraction, and this varies inversely as the size of the particles; it ceases altogether if the soil particles are sufficiently large. When the ascending water reaches the surface of the soil it is lost by evaporation. This loss can be prevented by placing over the surface a layer of substance whose particles are too large to let capillarity take place between them.

For this reason the gardener hoes his flower-beds and the farmer tills the fields, so that somewhat large lumps may lie on the surface. This is important, however, only where the water-table is close to the surface, as it commonly is in humid regions.

To prove that evaporation is thus prevented two gas-jars of equal diameter are filled with thoroughly wetted sand. Over the surface of one a layer of loose soil, sawdust, or coco-nut fibre is put. The jars are weighed at regular intervals, and the loss of weight which is sustained by the jar in which the surface of the sand is uncovered, is found to be far in excess of the loss in the other jar.

Special Features of Clay Soil.

The foregoing experiments have shown that water passe very slowly through clay soil, and that a great deal of water i held by the clay. A soil which contains a larg proportion of clay is therefore very rich in foo materials. It does not necessarily follow tha plants which are growing in it will be able to avai themselves of the food supplies, because the soil is badl aerated; it is "heavy," cold, and water-logged.

Clay in itself is not very heavy. In fact, if equal weights sand and clay be dried in the oven at 100° C. until all th water has been driven off, the residue of clay weighs less tha that of the sand. Clay is "heavy" because of the amoun of water contained in it.

Clay soil is cold. The water that lies in the interstice between the soil particles warms up much more slowly tha air, under similar conditions. Further, the soil loses muc heat from the evaporation of water at its surface.

Clay soil is water-logged. Water in itself is not harmful. In fact, plants can be grown in it quite successfully if sufficient air is blown through it. But the presence of excess of water in a soil must necessarily mean a deficiency in air and consequent interference with the respiration of roots and of Bacteria (pp. 253, 445).

As water soaks into the soil the clay becomes very much swollen ; it gets sticky and slippery and difficult to walk on. It sometimes happens that when an inclined bed of clay lies below the surface it becomes so slippery after heavy rains that the soil and subsoil, and any other layers which are lying on the top of it, slide down the slope. The well-known landslips along the south coast of England and the Isle of Wight have been caused in this way.

Neither water nor air can penetrate pure clay, such as modelling clay. To prove this, a disc of perforated zinc covered with a layer of clay is put in a funnel over a beaker. Water is then poured on the clay, but none passes through to the beaker. To prove the impermeability of clay to air, it is only necessary to plug the end of a piece of glass tubing with clay, and then try to blow air through it into a vessel of water ; no bubbles appear in the water, thus showing that no air has been able to get through the clay. If lime-water is used there will be no milkiness (p. 391).

When clay is dried it loses its stickiness and slipperiness, but regains them again on being wetted. If, however, it is burnt it loses these characters permanently and can never regain them. Burnt clay is permeable both to air and water, and is familiar to all in the form of bricks.

Now, pure clay consists of hydrated silicate of aluminium, which means that it is a substance made up of aluminium silicon, and oxygen. These substances are not essential plant food—a little silicon is generally present in the plants, but they grow equally well without it (p. 436). The importance of clay, then, does not consist in the material of which it is made, but in the size of the particles of that material. The clay itself is unaltered by the growth of plants in it. It simply provides a suitable physical environment from which solutions may be absorbed and in which plant roots can fix themselves. Because of the small size of its particles a clay soil is water-logged, cold, and badly drained. As a result it is difficult to cultivate.

To make a clay soil satisfactory something must be added to it which will make its particles hold together a little. This may be achieved by adding lime, when a rich and well-drained soil is formed.

The effect of lime on clay is seen in either of the following simple experiments :

Water is added to powdered clay in two gas-jars. They are well stirred until they are uniformly turbid. After adding a little lime-water to one of the jars they are left to settle.

Or, powdered lime is added to one of two portions of powdered clay soil. The samples of soil are then stirred up in two glass vessels and left to settle. In both cases the clay to which lime has been added sinks much more rapidly than that without lime, thus testifying to the larger size of the particles. The lime does not unite chemically with the clay ; it simply causes the clay particles to adhere in little flocculent masses.

Another beneficial effect that lime has on clay is the counteraction of "sourness." Sourness is often produced in ill-drained soil which lacks oxygen ; it arises from the presence of acids, which are formed in the decomposition of proteids by putrefying bacteria. The lime neutralises the acid and so "sweetens" the soil and makes it more favourable for the growth of plants and useful micro-organisms.

Special Features of Sandy Soil.

A soil in which the proportion of sand is large is a very sterile one, since little water is retained by it. A certain amount of sand in a soil is valuable, as it lightens the soil, that is, it makes it more permeable to air. The large amount of air that is contained in it makes a sandy soil very warm, because the temperature of the air between the soil particles rises with the temperature of the atmosphere.

A sandy soil is never sticky because the grains are loose. It is therefore easy to cultivate. Grains of sand vary considerably in size. On examination under the microscope they have a clear, glassy appearance.

Sand is formed from the substance quartz, or silica, which is made up of silicon and oxygen. These substances are not essential for the food of plants (p. 436). It follows, therefore, that sand, like clay, merely forms a physical basis in which a plant may root itself, and from whose spaces it may obtain water. It is unaltered by the growth of plants in it.

Chalk is the amorphous form of carbonate of lime; limestone is also carbonate of lime, but in the crystalline form.

Special Features of Chalky Soil.

A chalky soil is not comparable to one of sand or clay. It is not, as these are, simply an environment composed of unalterable grains of a suitable size, in which a plant can root itself, and from which it can draw water.

The chalk in a soil is a variable factor. Chemically it is calcium carbonate or carbonate of lime, and this changes very rapidly to calcium bicarbonate, which is soluble in water. Calcium is a very valuable plant food, and, as calcium bicarbonate is soluble, it can be absorbed by the roots. Chalk thus differs essentially from sand and clay, neither of which contributes any food to plants.

Owing to its solubility the chalk in a soil is constantly getting washed away. So much is this the case that a sedentary soil (p. 424) resting on the top of chalk rock may have had all the chalk washed out of it. Water in a chalk country always contains a certain amount of lime.

Chalk cliffs and quarry faces are familiar to those who know the coast and the downs of the south-east of England. The chalk was originally deposited under the sea, and is largely made up of the cases of minute sea-animals. It is very white and homogeneous-looking.

The depth of soil and subsoil in a chalk district is often only a few inches thick, so that the surface of the soil is very near the solid rock below.

A large number of plants thrive on chalk. As a result, the flora of a chalk country is very varied and beautiful. In the absence of chalk or lime some plants will not live at all: the Greater Celandine, Rock Rose, Wayfaring Tree, and Spindle are only found in chalk or limestone districts. On the other hand, chalk is actively antagonistic to some few plants: Foxglove and Rhododendron will not grow at all in chalky soil.

From the foregoing descriptions of sand, clay, and chalk it is obvious that a good soil to cultivate from the point of view of water-content, is one that contains a certain proportion of all these constituents. The sand lightens and aerates the soil. The clay provides good capillary tubes for the movement of water. The chalk acts on the clay, neutralising its acids and making its tiny particles cohere; it also provides a little calcium food which the plant requires.

Loam.

Such a soil, in which no one ingredient predominates, is distinguished as a loam.

In addition to sand, clay, and, in some cases, chalk, loam contains the remains of living things. It is to this humus, formed very largely from the decay of roots, that its dark colour is due.

Humus.

As humus is of organic origin it can be removed from soil by burning, so that only the inorganic constituents remain. A small quantity of earth is heated in a crucible over a Bunsen burner. As long as a smell like that of burning wood is noticed, the heating should be continued. As it cools, the residue in the crucible turns brick-red. It is, in fact, "terra-cotta."

In Central and Western Canada, the roots of most plants penetrate the soil to depths of two feet or more, and considerable water is undoubtedly obtained at these depths. Nevertheless, the bulk of the food material is absorbed from the humus-containing layer near the surface. For this reason it is most important, when digging or trenching, to keep the soil and subsoil distinct, and to replace the soil on the top at the end of the operation.

The humus-containing layer is seldom very thick. It usually varies from about 6 to 12 inches. It is readily distinguished from the subsoil, which is always lighter in colour.

The humus in the soil is in a state of constant change. As the organic matter of which it is composed decays, different substances are formed, some of which are soluble and are thus capable of providing plant food.

Leaf-mould.

Leaf-mould is a humus formed from decaying leaves. When a heap of leaves is left to rot, the heap gradually gets smaller and the forms of the leaves become less distinct. In a year or two the heap has been reduced to a dark brown, powdery substance in which isolated bits of leaves are here and there distinguishable. This is termed leaf-mould.

When roots of plants decay in very badly drained soil, so that the actual decay takes place under water, a form of humus termed peat is produced.

Peat.

The conditions of its formation make peat unfit for plant growth. It contains marsh gas as well as other poisonous gases and it is very acid.

Water causes peat to swell, so that peat moors may become very dangerous after heavy rains.

The Soil Water.

It is now clear that soil is made up of various solid particles, and that the soil-water contains substances in solution which form the food of plants. The presence of chalk in the soluble form of calcium bicarbonate has already been noted. As other rocks disintegrate various mineral salts are formed, some of which dissolve in the soil water. Other soluble substances are produced by decay of the organic constituents of the soil.

A large number of salts are found when soil-water is analysed. Among these the following most commonly occur:

Substances in Solution in Soil Water.

Sodium chloride (common salt), containing the elements sodium and chlorine.

Sodium sulphate (Glauber's salt), containing the elements sodium, sulphur, and oxygen.

Magnesium sulphate (Epsom's salt), containing the elements magnesium, sulphur, and oxygen.

Calcium sulphate (gypsum), containing the elements of calcium, sulphur, and oxygen.

Traces of chlorides, nitrates, and phosphates of calcium magnesium and potassium, containing the elements chlorine, nitrogen, oxygen, phosphorus, calcium, magnesium, and potassium. Traces of iron salts.

Use made by the Plant of the Substances in Solution in Soil Water.

The elements thus available for the plants' use are sodium, chlorine, sulphur, oxygen, magnesium, calcium, nitrogen, phosphorus, potassium, and iron.

The mere presence of these salts in the soil water does not necessarily mean that the plant needs them for its growth. What salts are actually absorbed by the root may be determined either by *ash analysis* or by growth in *culture solutions*.

Ash Analysis.

When a plant has been burnt the ash that remains is always found to contain potassium, magnesium, calcium, iron, phosphorus, sulphur, silicon, chlorine, and sodium. In addition to these there were, of course, in the plant, those elements that have escaped during the burning.

Culture Solutions.

A normal culture solution is one that contains the soluble salts commonly found in the soil, in the proportion in which they occur.

A series of seedlings should be grown in glass vessels : one in a normal culture solution ; one in a solution in which nitrogen is omitted ; one in a solution in which calcium is left out ; and so on. In this way, leaving out one element only in each case, it is possible to find out which elements are useful, which essential, and which the plant can do without.

To get good results great care must be taken in setting up the apparatus. The vessels used must be large and chemically clean. Two glass tubes must be inserted through the corks by which the seedlings are supported, so that air can be blown in every day and fresh solutions added when required.

The solutions can be made up as follows :

Normal Culture Solution

1,000 c.c.	Distilled water
1 gramme	Potassium nitrate
·5 ,,	Calcium sulphate
.5 ,,	Magnesium sulphate
·5 ,,	Calcium phosphate
·5 ,,	Sodium chloride
a trace	Iron sulphate

Solution without Nitrogen

Potassium chloride to be used instead of potassium nitrate in N.C.S.

Solution without Calcium

Omit calcium sulphate and calcium phosphate in N.C.S. and include ·5 gm. ferrous phosphate.

Solution without Potassium

Calcium nitrate to be used instead of potassium nitrate in N.C.S.

Solution without Magnesium

Omit magnesium sulphate in N.C.S.

Solution without Phosphorus

Omit calcium phosphate in N.C.S.

Solution without Sodium

Potassium chloride to be used instead of sodium chloride in N.C.S.

Solution without Iron

Omit iron sulphate in N.C.S.

Solution without Sulphur

Omit calcium sulphate in N.C.S. Magnesium nitrate to be used instead of magnesium sulphate and a trace of iron chloride instead of iron sulphate.

Experiments with culture solutions are simple in theory. In practice they do not always give satisfactory results because of the difficulty in keeping them free from Moulds and Bacteria. They are, however, extremely instructive, and should be carried out if possible. If managed successfully the following results are obtained :

The plant in the normal culture solution grows healthily and well, showing that it has all it requires.

Of the others, the one without nitrogen makes no headway. Those lacking sulphur and phosphorus scarcely fare any better.

The plant without iron is lacking in colour or *chlorotic*, showing that iron is required for the formation of chlorophyll.

The effect produced by the omission of the other elements is not so marked. Without potassium, magnesium, and calcium the plant cannot grow normally.

In the absence of calcium the leaves are yellowish. The starch produced in them is unable to get away, so that there is an abnormal accumulation of starch in the leaves.

Without magnesium the colour of the leaves is also affected. They are spotty and dirty brown.

Although sodium, chlorine, and silicon are always present in plant ash, plants grow perfectly well without these elements.

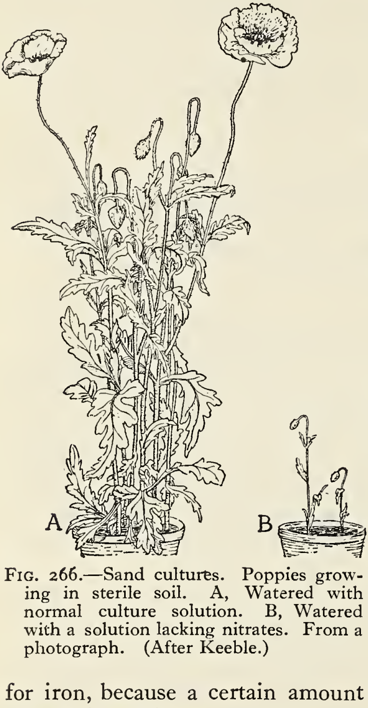


Fig. 266.—Sand cultures. Poppies growing in sterile soil. A, Watered with normal culture solution. B, Watered with a solution lacking nitrates. From a photograph. (After Keeble.)

Sand Cultures. These experiments can be carried out, too, by means of *sand cultures*. Good silver sand is well washed with dilute sulphuric acid. This washing is followed by repeated rinsings, first with tap water, then with distilled water.

The best results are then obtained by sowing seeds which normally grow in a sandy soil. Poppies are a good choice. The little "plots" are watered with distilled water until the cotyledons appear, and after this with the appropriate culture solution (Fig. 266).

This method cannot be used to test the need for iron, because a certain amount of this element is always present in sand.

It has now been established that the substances that a plant needs are suitable compounds of nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, and iron. Small amounts of other substances are also found to be beneficial.

Since the protoplasm of which living things are composed is made up of carbon, oxygen, hydrogen, nitrogen, sulphur, and phosphorus, it follows that a constant supply of these elements must be always available for the plant's requirements if any growth is to take place. The above experiments have shown that nitrogen, sulphur, and phosphorus are taken from the soil, and it is already known that carbon is obtained from the carbon dioxide of the atmosphere and hydrogen and oxygen from the water of the soil (p. 309).

Origin of the Substances Present in Soil Water.

With the exception of nitrogen all the elements present in salts dissolved in soil-water have an inorganic origin; they have been produced in those disintegrating processes of the rocks which form soil.

Disintegration of rocks does not, however, yield nitrogen. The derivation of the nitrates of the soil is therefore a separate problem.

Nitrogen Present in Air.

Nitrogen occurs in large quantity in the air, forming four-fifths of the atmosphere. It has already been seen that this is not a direct source of nitrogen to plants; seedlings in culture solutions that contain no nitrogen cannot grow, although they are surrounded by atmospheric nitrogen.

Source of Nitrates in Soil Water.

Certain facts have now been established with reference to the presence of nitrogen and nitrates, and some deductions can be drawn from them.

(1) Plants will not live without nitrogen.

(2) Plants take in nitrogen in the form of nitrates.

(3) Nitrates cannot be formed by the breaking down of the rocks, since these contain no nitrogen.

(4) Nitrogen is a constituent of all living things, and is therefore a constituent of the humus of the soil.

(5) It may therefore be inferred that a plant gets its nitrogen from the humus.

Experiments can now be made to test the validity of the inference just stated.

Soil and subsoil are collected from the same place and seeds set to grow in a pot of each. The seeds sown in the soil grow healthily, while those in the subsoil make little or no growth (Fig. 267). Now, the difference between soil and subsoil is that the former contains organic remains, and it is thus seen that the capacity for sustaining growth which is possessed by the soil, but is lacking in the subsoil, is due to the humus contained in the former.

The Production of Nitrates from Humus.

If the soil used in the last experiment is baked before the seeds are set to grow, the soil will behave in the same way as the subsoil, and very little growth will result. This suggests at once that the conversion of humus into nitrate is brought about by living organisms which are destroyed when the soil is baked.

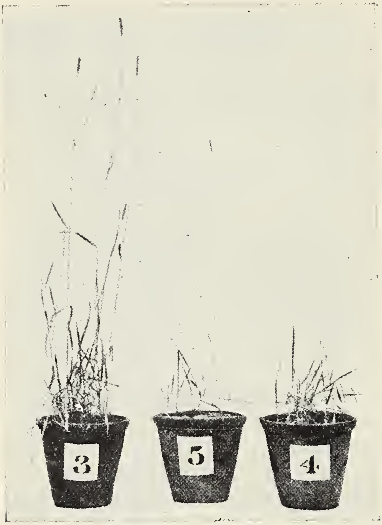


Fig. 267.—Rye growing in surface soil (Pot 3), subsoil (Pot 4), and sand (Pot 5). (After Russell.)

A further experiment bears this out. Two sets of seedlings are grown for some time in different pots. They are uprooted and a further set is grown immediately in one of the pots. The resulting yield is very poor and indicates that the available food has already been used up. The second pot of earth is left fallow in a damp place for a considerable time. It then supports a second crop of seedlings quite successfully. Evidently the food content of the soil has been renewed while the pot was left in the damp atmosphere. This renewal depends upon living organisms in the soil which are continually producing nitrates, provided the soil is kept damp.

Further corroboration of the existence of minute living organisms in soil is obtained by a very simple experiment. Such organisms, if they occur, must use up oxygen and produce carbon dioxide in respiration : a little damp garden soil is tied up in a muslin bag and suspended in a corked flask over lime-water. The lime-water soon turns milky (p. 391). In a corked flask without soil the lime-water remains clear.

Thus it is proved that there are living organisms in soil, and that these need air to breathe. This is one of the chief reasons for keeping land well drained.

The amount of food substance present in soil at any given time is very small. If some soil is dried and weighed, cropped with something, then dried and weighed again, little, if any, difference in weight is detected.

To test for the presence of nitrates, soil is dried and put into a funnel with filter paper. A little water is then allowed to pass through it. To a few drops of this water three or four drops of diphenylamine sulphate are added, followed by three or four drops of strong sulphuric acid. A deep blue colour indicates the presence of nitrates.

The breaking down of the complex proteid substances of humus is brought about to some extent by fungi, but it depends chiefly on minute unicellular plants termed Bacteria, which live in the soil in vast numbers.

Bacteria.

The following experiment demonstrates their presence :

Into each of two flasks a little milk is put ; the necks of the flasks are lightly plugged with cotton-wool and the flasks are then gently brought to the boil. When the milk is cool a small quantity of baked earth is put into one of them ; a similar quantity of unbaked earth is put into the other. The following day the milk which contains the unbaked soil will be sour. The milk containing the baked soil will still be sweet. On examination of some of the sour milk under the microscope rod-shaped Bacteria are seen.

In order to carry on their work Bacteria need warmth, air, moisture, and organic matter, and it is the chief aim of cultivation to supply these needs.

The decaying animal and vegetable remains in the soil are continually being broken down from complex proteids to simpler substances. Firstly a large number of putrefying Bacteria (p. 446) set to work upon them ; this is particularly the case with animal remains. After this, other Bacteria continue the breaking-down process until compounds of ammonia (NH_3) are produced, together with carbon dioxide and water. At this stage a strong smell of ammonia can always be detected.

The Bacterium, Nitrosomonas, then acts on the ammonium salts and converts them into nitrites; after this another Bacterium, Nitrobacter, converts the nitrites into nitrates. The process of oxidation of ammonium compounds into nitrates is termed *nitrification*.

In this way nitrogen is brought into a form in which it can be absorbed by plants.

There are certain other Bacteria that are able to increase the nitrogen content of the soil by using free atmospheric nitrogen. These have the power of building up the proteid substances of their bodies by the absorption of nitrogen from the atmosphere. When they die, therefore, the soil is enriched and its nitrogen content is increased. Some of these Bacteria always live in association with plants belonging to the family Leguminosæ in little root-tubercles (p. 389).

The Nitrogen Cycle.

It follows, therefore, that a constant *circulation of nitrogen* is going on in nature. Green plants use the simple nitrate and build up complex proteid substances. Bacteria break down these proteid substances into simple nitrates. Both the building up and the breaking down processes are the work of plants. Animals simply absorb the proteids, incorporating them into their own bodies.

Increase in the actual amount of nitrogen in the soil can only be achieved by getting it in some way from the atmosphere, and thus the work of the Bacteria that are able to utilise free nitrogen is of the utmost importance and value.

CHAPTER XXIX

BACTERIA

DECAY is one of the first necessities of life; without it life would soon cease. The world's surface would become covered with a vast collection of dead bodies and the amount of food available for the plants and animals that still lived would become less and less until finally none would remain. This is one explanation of the great importance of Bacteria to all other forms of life.

When the milk turns sour; when the joint gets "high"; when there is a bulge in the tin of canned fruit; when the patient suffers from pneumonia or influenza; the cause is to be found in the growth and activities of these minute organisms.

No sooner are animals and plants dead than Bacteria set to work to bring about their destruction. Proteids, carbohydrates, and fats are all broken up. The final products of the destruction are nitrates, carbon dioxide, water, sulphuretted hydrogen, marsh gas, and hydrogen.

To understand Bacteria, however, they must be looked at from their own point of view, rather than entirely from the point of view of other living things whose lives they affect. Bacteria themselves are not concerned in being either public benefactors or public scourges; they are simply minute living organisms that require food and energy for their own growth and for the reproduction of their species.

Structure.

An abundant growth of Bacteria can be obtained in a few days by chopping up some hay, putting it in water, and then leaving it to stand in a warm place. Soon a gelatinous film forms on the surface. This is due to the growth of innumerable Bacteria, whose jelly-like outer coverings cohere to form a slimy mass. On examination of a drop of the water under the microscope tiny rod-like micro-organisms are seen (Fig. 268).

Without microscopes of higher power than those usually available in schools it is impossible to investigate the actual structure of Bacteria.

They are very minute, colourless, unicellular plants, and are among the smallest of known organisms.

They are classed as plants because they take in food in the liquid or gaseous form, generally the former. They have no chlorophyll, but some of them are able to live on inorganic substances, as the green plants do, manufacturing glycogen, a substance that is allied to starch and which is always present in their protoplasm. Usually, however, they feed on highly organised plants and animals.

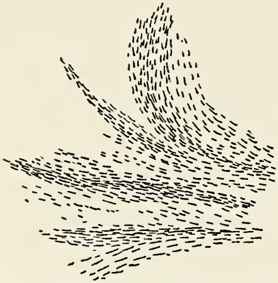


Fig. 268.—Hay bacilli in rows in jelly-like substance.

There is a very simple group of water plants termed the Cyanophyceæ, or Blue-green Algæ, with which the Bacteria appear to have affinities. The two groups are alike in their simplicity of structure, in their general life-history, and in their method of division by fission. It may be that life first manifested itself in some such simple forms as these. The primitive forms of life must have lived in water and probably they obtained energy in different ways, some directly from light, others from oxidation or other similar chemical process.

Bacteria vary in form, being spherical, rod-like, filamentous, or spiral.

The spherical forms are distinguished as *cocci* or *micrococci* ; rod-like forms are termed *bacilli* ; a slightly undulate form is named *vibrio* ; spiral forms are termed *spirilli* (Fig. 269).

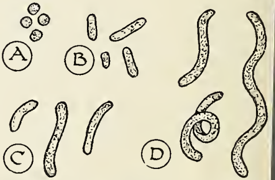


Fig. 269.—Diagram of differen forms of bacteria. A, coccus B, bacillus. C, vibrio. D spirillum.

All the forms may break up into spherical units or micrococci. Micrococci generally multiply very rapidly by fission

The rod-like individuals may be joined end to end to for long filaments ; the cocci may form chains or *masses* (Fig. 270)

Notwithstanding their affinities with plants, bacterial cell are not bounded by a cellulose wall. The limiting layer appears to be of a protein substance.

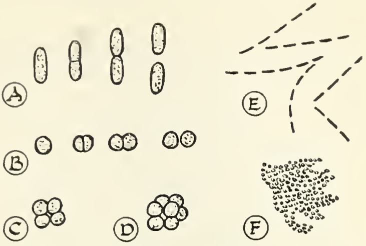


Fig. 270.—Diagram showing division of Bacteria. A, division of a bacillus. B, coccus dividing to form a chain. C, coccus dividing in two directions. D, coccus dividing in three directions. E, chains of bacilli. F, group of micrococci.

This layer produces a jelly-like film round each individual. It is by this film that individuals are held together, thus producing the filamentous and chain-like forms. Sometimes the jelly-like films swell greatly, so that a large mass of jelly-like substance is produced as a result of the fusion of the layers of the individual units. When in this state the Bacteria are described as being in the *zooglœa* phase.

The protoplasm within the cell is not clearly differentiated into nucleus and cytoplasm. The whole contents pick up nuclear stains. It is therefore probable that the material which is usually included within the nucleus in cells of higher plants, is here diffused throughout the whole protoplasm. At the same time it must be remembered that the cells are so extremely minute that detailed investigation is most difficult.

Movement.

Bacteria are frequently motile. Movement is brought about by the lashing of cilia (p. 11). These may cover the whole surface, or be restricted to the ends, or to one end only, or there may be only a single cilium (Fig. 271).

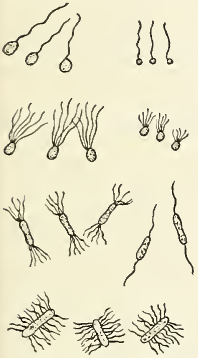


Fig. 271.—Diagrams showing arrangement of cilia in different kinds of Bacteria.

It is not possible to see the cilia in the living specimen, as they are so transparent, but the movement of the Bacterium, which is due to their action, can be watched. They are made visible in the dead organism by deep staining.

Reproduction.

Bacteria reproduce by fission with amazing rapidity. Fission may occur as frequently as once every twenty or thirty minutes ; consequently one individual, by dividing once every half-hour, will produce over a million descendants in less than ten hours !

Rate of multiplication depends on amount of food and suitability of temperature. When conditions are adverse another method of reproduction is resorted to in some species. This is the method of spore formation. The contents of the bacterial cells become rounded off and a thick resistant wall is formed within each mother-cell wall. In time the wall of the parent cell dissolves and the spore is free. Only one spore is formed from each cell, therefore this is not a method of multiplication of individuals. It is really a resting stage during unfavourable conditions. The spores are very resistant. They can withstand a high temperature and a considerable degree of desiccation. As a matter of fact, a bacterial spore is the most resistant form of living protoplasm known. In this form Bacteria are dispersed far and wide They are carried on air currents, and under suitable condition may germinate far from their place of origin.

No method of conjugation or of sexual reproduction ha been observed in any species of Bacteria.

The Effect of External Conditions on the Growth of Bacteria.

Bacteria are almost ubiquitous. They occur in every conceivable situation. Both air and water are alive with them they do not, however, float long in the atmospher but tend to accumulate on all surfaces. The gather round the bases of cut flowers in water, an thus prevent the water from rising up the stems hence the advisability of cutting off the ends of th stems each day. They do not like high altitudes, and mountai air is almost devoid of them. In a comparison of the air a the top of St. Paul's Cathedral with that of the churchyar below, Bacteria were found to be present in a ratio of 1 to 1 The discovery of Bacteria in hailstones, however, proves th they do float upwards to a considerable height. Their grow is affected by light, heat, oxygen, water, food, and various chemical substances.

Effect of Light on the Growth of Bacteria.

Most Bacteria grow well in feeble light. Direct exposure to sunlight is harmful to them. For this reason water that is to be used for drinking is exposed to sunlight in open reservoirs. The blue, violet, and ultra-violet rays are the most destructive to them.

Effect of Heat on the Growth of Bacteria.

The amount of heat required by Bacteria is very varied. For common species the minimum temperature is 1°–10° C., the optimum 25°–35° C., and the maximum 42°–50° C. Many species thrive at much higher temperatures than these, but the majority are killed if the temperature is raised to about 55° C. All, when in the active condition, are killed by boiling water.

On the other hand, Bacteria can resist very low temperatures. At 0° C., the freezing point of water, activity is suspended, because the activity of protoplasm itself is checked at this temperature. But the Bacteria are not killed, and they resume activity when the temperature rises.

In the spore stage Bacteria are much more resistant. Bacterial spores can even withstand prolonged boiling.

The chief interest of Bacteria is physiological and is bound up with their methods of obtaining food and energy.

Methods of obtaining Energy.

In most living things energy is liberated by the *oxidation* of substances that have been absorbed as food. Oxidation is a form of combustion. In the combustion of coal, carbon is oxidised into carbon monoxide and carbon dioxide, with liberation of energy in the form of heat and light. Oxidation in living organisms takes place at ordinary temperatures and is termed respiration. Respiration, then, is a process by which energy is made available and which requires a constant supply of oxygen.

A large number of Bacteria must have free oxygen for respiratory purposes ; some can do without oxygen for a time ; others, again, cannot live in its presence. The latter are *anaerobic*. Those that need oxygen are *aerobic* and get available energy by respiration, that is, by oxidation either of their own tissues, or of the tissues of the host on which they live.

All Bacteria must have some supply of energy in order to carry on their activities. When this supply results from the destruction of a host without oxidation the process is termed *fermentation*, and has been described as " life without oxygen." Recently this term has been extended to certain manufacturing processes in which oxygen plays some part.

When fermentation of proteid substances takes place it is accompanied by the evolution of offensive gases. Such fermentation is *putrefaction*.

Putrefaction of proteid substances is brought about by a series of different Bacteria, each being responsible for one step of the process. The bad smell which results when organic remains are putrefying, as, for example, in a heap of rotting leaves, can be removed by letting in air. The evil-smelling compounds are oxidised into non-smelling substances.

Methods of obtaining Food.

The vast majority of Bacteria feed, as animals do, on highly organised substances, such as proteids and carbohydrates. They live either as parasites or saprophytes (p. 456). They act on the food substances very much as do the enzymes in the alimentary tract of animals. They digest, then absorb, the food.

While all animal life is infested with parasitic Bacteria, living plants are almost entirely free from them. Those that occur in the root-tubercles of many members of the Leguminosæ are symbiotic rather than parasitic (p. 389).

Some few Bacteria are able to build up their food as green plants do, using simple inorganic substances. Some of these use the carbon dioxide of the atmosphere in the manufacture of carbohydrates.

The micro-organisms that are able to build up their own food from inorganic materials are the *Sulphur*, *Iron*, and *Nitrifying* Bacteria. As they contain no chlorophyll they cannot obtain energy directly from sunlight. They obtain the necessary energy, therefore, by other means :

(1) The Sulphur Bacterium gets the energy for food-building by oxidation of sulphuretted hydrogen (H_2S), that is present in ponds and marshes :

$$2H_2S + O_2 \rightarrow 2H_2O + S_2.$$

The sulphur that is produced in this reaction is stored in the protoplasm of the Bacterium in the form of granules. The vast deposits of sulphur that occur in Sicily are due to the activities of Sulphur Bacteria.

(2) The Iron Bacteria are found in stagnant pools that contain soluble bicarbonate of iron. In such pools sulphuretted hydrogen is always present; when this interacts with the iron salt, iron sulphide is produced. The Bacteria get the energy they need by oxidising this iron sulphide, the process resulting in a brown deposit of ferric hydroxide.

(3) The Nitrifying Bacteria have already been described (p. 440). Of these, one obtains energy by oxidising ammonium salts to nitrites, and the other by oxidising the nitrites to nitrates.

There is a small group of Bacteria that is able to make use of the free nitrogen of the atmosphere. The way in which they get their energy is obscure. Those that live symbiotically in the root-tubercles of many Leguminosæ (p. 389) have a similar power, but they, of course, may derive energy from the breaking down of the carbohydrates of the plant with which they are associated.

All these forms are little understood. Their interest lies in their power of building up food substances from simple inorganic materials. This is a power that makes them independent of all other living things and suggests their possible relationship to the first formed organisms of the world. Those among them that are able to fix free nitrogen play a most important part in adding to the available supply of nitrates in the soil.

One small group of Bacteria undoes, to some extent, the useful work of Nitrobacter, which oxidises nitrites to nitrates. This is the group of the *de-nitrifying Bacteria*. Their effect seems to be entirely harmful. When they are in a state of oxygen-poverty they get the gas by reducing nitrates to nitrites, with evolution of free oxygen.

Need for Water. Water is absolutely essential for the growth of Bacteria, as it is for all living things. Spores, however, survive great desiccation.

Effect of Certain Chemicals.

Bacteria are killed by the presence of a number of chemical substances. Among these are boracic acid, carbolic acid, and iodine. For this reason these substances are used as antiseptics (p. 450).

Heat and Light produced by Bacteria.

The metabolic processes of the Bacteria are often associated with great heat and light. "Spontaneous combustion" may occur in a hayrick that has been made while the hay was damp, thus giving a suitable environment for bacterial growth.

Many marine Bacteria are phosphorescent. Bones and scraps of meat lying on dust-heaps near the sea get infected and shine at night with a phosphorescent light. Even the meat in the butchers' shops may glow in the same way.

So far Bacteria have been studied from their own standpoint as living organisms needing food and energy for their growth and multiplication. But because of their saprophytic, or parasitic, mode of life, they are responsible for many changes which affect the world in general.

Bacteria and Manufacturing Processes.

It was the great French chemist, Pasteur, who discovered that fermentation and putrefaction were brought about by living organisms. Many manufacturing processes depend upon fermentation. This is true of the manufacture of cheese from milk and of vinegar from alcohol.

Cellulose Digestion and Circulation of Carbon.

The decomposition of cellulose which is such an important constituent of plants is brought about by Bacteria. The process is accompanied by evolution of marsh gas (CH_4) and sulphuretted hydrogen (H_2S). In a pond where there is a large amount of vegetable refuse, a smell of sulphuretted hydrogen can always be detected, and bubbles of marsh gas are liberated by stirring up the decaying matter with a stick.

The higher animals do not produce a special enzyme for the digestion of cellulose, although so much is eaten by herbivorous creatures. They rely on the co-operation of Bacteria. These cellulose-digesting Bacteria occur in large numbers in the complicated stomach of the ruminants and in the intestine of the horse. Here there is very little available oxygen, and much of the cellulose remains undigested. The rest is only partially oxidised and a good deal of marsh gas (CH_4) is formed.

In man cellulose is not digested, but it plays a useful part in preventing constipation.

It is thus evident that Bacteria are in part responsible for the *circulation of carbon* in nature. The green plant absorbs carbon dioxide and water and builds up carbohydrates, including cellulose. The cellulose-destroying Bacteria act on the cellulose, breaking it up into carbon dioxide, marsh gas, and water.

Bacteria and Disease.

A large number of the diseases of man and the lower animals are due to parasitic Bacteria. Some of these live naturally in soil containing organic material; it is only occasionally that they enter the bodies of animals. These are *partial* parasites. Others live entirely in animals and are termed *complete* parasites.

Since parasitic Bacteria carry out all their metabolic processes within the host it is to be expected that the host will be greatly influenced as a result. The Bacteria may be perfectly harmless to their hosts. They are harmful when they produce poisonous secretions, or toxins (p. 183).

Such toxins would invariably kill the hosts in time were it not for the production of antitoxins in the blood and the activity of phagocytes (pp. 182, 183). Contagious diseases are due to complete parasites.

Bacteria that cause infectious diseases are able to live for a time outside the body. They are carried in the air, and it is for this reason that the disease spreads, or is "caught." Sometimes the germs are carried by an individual who is merely a "carrier." Such a person does not suffer himself from the disease, but may cause its outbreak in any place he visits.

The soil is the normal habitat of some Bacteria, and they only enter the human body occasionally. The *tetanus bacillus* (Lockjaw) is of this type. It occurs in all soils that are manured with horse or cow-dung. The Bacterium lives in the intestines of these animals, generally without doing them any harm, and the spores can pass long resting periods in the soil. It is for this reason that it is so important to treat with iodine any scratch received while gardening.

Bacteria of this class can only get into the body by means of a scratch or wound. They cannot penetrate the skin, but, having once gained an entry, they get into the blood-stream and there produce the toxin. The Bacterium which causes hydrophobia is introduced with the saliva on the teeth of a mad dog. Insect bites of various kinds are responsible for the entry of Bacteria that produce plague and other diseases (p. 453).

The understanding of the part played by Bacteria in entering the body through a wound is due to the work of Joseph Lister, afterwards Lord Lister. He was the first to treat wounds with substances that kill Bacteria. Such substances are termed *antiseptics*. In these days preventive or aseptic methods are adopted in all surgical operations; all instruments that are used are carefully sterilised to guard against bacterial infections.

Food and Bacteria.

An understanding of the universality, the persistence, and the activities of Bacteria, makes it clear that the greatest care must be taken to prevent their access to food. There are various ways of accomplishing this end.

Sterilisation.

A dry temperature of 160° C. for half an hour, or of 180° C. for ten minutes, is enough to kill all Bacteria, including the spores.

To sterilise a liquid it should be gently boiled in a flask for several minutes with a plug of cotton-wool in the neck. All active Bacteria are killed and the plug prevents the entry of others as the flask cools. If, however, there were Bacterial spores in the liquid these may have survived. It is well, therefore, to ensure complete sterilisation by boiling two or three times in succession. Between each boiling the flask should be left in a warm place so that the spores may germinate and thus lose their resistant qualities.

Treatment of Milk.

Milk can, of course, be sterilised by boiling. This process however, rather spoils its flavour. Milk supplied to our large towns is now frequently "pasteurised." To this end the milk is kept at a temperature of 68° C. for twenty minutes, as it has been determined that this is sufficient to kill all the Bacteria.

To rid water that is to be used for drinking purposes of Bacteria, it is passed through several feet of sand or a mixture of sand and charcoal. A film forms on the surface of the sand and this catches the Bacteria. Alum or some other uninjurious substance is sometimes used to produce the film artificially.

Filtration of Water in Reservoirs.

There are many ways in which food may be preserved from infection. The following are the chief:

Methods of Preserving Food.

(1) *By cold.* Food may be kept in a refrigerator. Bacteria are not thereby killed, but their action is checked.

(2) *By preventing access of air.* This is the principle underlying the preservation of eggs in water-glass. The method is perfectly satisfactory if the eggs are free from infection at the start.

(3) *By drying.* As a rule Bacteria do not grow if the water content falls below about 25 per cent. Dried peas and lentils can be kept indefinitely. So, too, can dried fruits.

(4) *By heat.* This is the method used in the canning of fruit and vegetables. The cans are heated and then hermetically sealed so that no Bacteria can enter after the heating. Although this method is generally satisfactory, there is always the danger that some resistant spores may have survived the heating process.

(5) *By the action of preservatives.* A common preservative is salt, which is used for fish, pork, etc. Salt does not kill Bacteria, but their growth is checked by it. Another preservative in general use is sugar, which is used to preserve fruit in the making of jam. It is used, too, in the preparation of condensed milks. Many chemical substances are used as preservatives, such as formalin, boracic acid, and salicylic acid. As these are often extremely harmful, especially to young children, the law requires their notification when they are used commercially.

CHAPTER XXX

PARASITES AND SAPROPHYTES

Looking on the seamy side of life, much is disclosed that is harsh, cruel, and ugly. Nature, in the widest sense of the term, is not " beautiful in all her moods," and one of the most unpleasant phases is found in a study of parasitism.

Among living things, at different evolutionary stages, individuals are found preying one upon another. One organism attacks another at a vulnerable spot, either weakening its prey or, in extreme cases, bringing about its death.

Animals are parasitic on other animals and on plants.

Plants are parasitic on other plants and on animals.

From our point of view there is something to be said to the credit of certain parasites. The Ichneumon Fly is responsible for limiting the number of Cabbage White Butterflies in the world, and thus preventing, to some extent, the depredations of a predatory horde of caterpillars (p. 59).

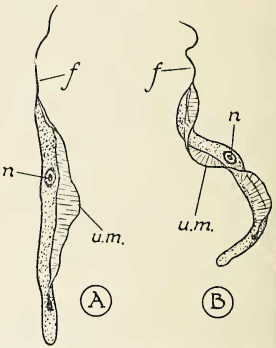


Fig. 273.—Diagrams of the flagellate *Trypanosoma gambiense* adapted from different authors. A, A mounted specimen. B, A living individual in active movement. *f.*, flagellum ; *n.*, nucleus ; *u.m.*, undulating membrane that co-operates with the flagellum in bringing about movement, and always waves to fill the " bays " of the flagellate.

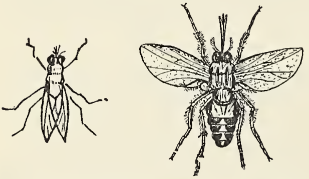


Fig. 272.—The Tsetse fly (natural size and enlarged) that inoculates man with sleeping sickness.

In most cases of parasitism it is, however, again from our point of view, useless to look for any beneficent aim in parasitic attacks.

Man, himself, is the host of many animal parasites.

Tropical Diseases.

The terrible "sleeping sickness" of West and Central Africa is caused by a protozoon, *Trypanosoma gambiense*, introduced into the blood of man by the bite of one of the Tsetse flies (Fig. 272).

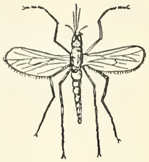


FIG. 274.—The Mosquito (*Culex*) responsible for Malaria (enlarged).

From the blood-stream the parasites pass into the lymph. They swim in this by means of a long flagellum and reach the fluid in the hollow spinal cord (Fig. 273). In the brain each artery is surrounded by lymph, whose work it is to protect the extremely delicate brain tissue from even such a slight shock as the pulsing of an artery. To these small lymph canals the flagellate protozoa make their way. They cause drowsiness that cannot be overcome, a wasting away of the body, and, ultimately, death.

Malarial fever results from inoculation by "mosquitoes" (anopheline flies, Fig. 274). As these flies pass their larval and pupal stages in water, one means of stamping out many parasitic tropical diseases is to drain marsh lands and so bring about their death. The larvæ of the flies come up to the surface of the water to collect supplies of atmospheric air. If the thinnest possible film of oil is allowed to spread over the surface of the water, their breathing is interfered with. This is another means of extermination.

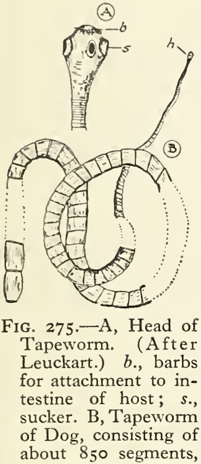


FIG. 275.—A, Head of Tapeworm. (After Leuckart.) *b.*, barbs for attachment to intestine of host; *s.*, sucker. B, Tapeworm of Dog, consisting of about 850 segments, in which eggs are produced and fertilised. *h.*, head.

Flatworms and Threadworms are human parasites in all parts of the world.

The Tapeworm is one of the commonest. The adult worm may be many feet in length (Fig. 275). Its embryo stages are frequently swallowed by pigs in their, often unhygienic, food. They are the cause of "measly pork." In some parts of Europe, where pork is eaten in a semi-raw state, diseases caused by the Tapeworm are rife among the human population. The measly condition of the pork cannot be detected by the unpractised eye. The safeguard is very thorough cooking. This advice applies to all meat, not to pork alone.

The Tapeworm.

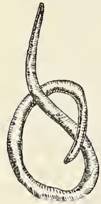


FIG. 276.—Ascaris.

Another very common parasite in man is the Human Roundworm, *Ascaris lumbricoides*. These worms are most unpleasantly white. They have a very muscular body wall and move with abrupt twists (Fig. 276).

Ascaris.

The male is usually about 7 inches long. The female reaches a length of 17 inches and lays, on an average, 1,500 eggs daily. This enormous power of reproduction is characteristic of parasites and is their counter-stroke to the long odds that are against their finding their particular host.

The Roundworm has neither respiratory nor vascular systems. Its alimentary canal is of the narrowest because, as it lives in the small intestine of man, its three-lipped mouth takes in solid or liquid food practically digested.

The eggs are expelled with the human fæces. The conditions for their development are a certain amount of moisture, a temperature above 60° F., and an area free from putrefaction. This last condition explains their expulsion from the host. The bacterial flora make their development impossible in the large intestine of man.

The tiny worms are swallowed in, or on, food. They pass to the small intestine and enter the capillaries of the villi (p. 159). Carried by blood and lymph they reach the lungs. Because of their size they cause congestion of the lung-capillaries. Hæmorrhage follows, and they are driven into the alveoli. Now, on their roundabout journey, they travel up the bronchi and trachea and get to the pharynx. They are now swallowed a second time and, passing down œsophagus, stomach, and duodenum, once more reach the coils of the intestine. During this circuitous journey the worms have increased in size from ·28 mm. to 2 mm.

Ascaris is universal. The safeguard against the parasite is just the exercise of reasonable care, especially, perhaps, care in the matter of drinking water. If this is polluted, certainly the Threadworm, in some stage, will be in it.

Cleanliness is the great weapon of defence against most parasitic attacks. Cleanliness, that is, in every direction: in yards and gardens (rubbish heaps are bad); in the care of dustbins as well as in bodily cleanliness and matters of the house; cleanliness, too, in the treatment of raw foods, whether these be animal or vegetable.

In some cases an individual may be utterly unaware that he is the host of a parasitic worm. In other cases the parasite may throw his whole constitution completely out of gear. As he must feed parasites as well as himself, he is, at times, voraciously hungry. At others he is sick, and the mere sight of food is distasteful. He may suffer from diarrhœa and anæmia. The parasitic action produces toxins in the blood which the anti-toxins do their best to overcome (p. 183). Temporary bronchitis is caused by the passage of the parasite in the lungs, and the whole bodily disturbance leads to various nervous diseases.

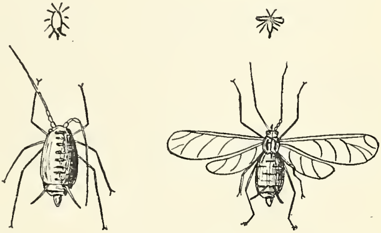


Fig. 277.—Larva and mature insect of the Green Fly of the Rose. The small figures are natural size.

The Green Fly (*Aphis*) is parasitic upon plants (Fig. 277). All the characteristics of the insect are concerned with the production of the greatest possible number of descendants to prey upon our summer plants.

Green Fly.

The female, throughout the summer, is parthenogenetic; that is, the eggs which she produces in tens of thousands develop without fertilisation. Not only this, but the young are hatched within her body; these are all female and are themselves capable of reproducing within two or three days.

Towards autumn both males and females are produced. As a result fertilised eggs are laid in the autumn, and, the following spring, give rise to females which carry on the traditions of the race.

It must be admitted that the behaviour of the Green Fly is only an exaggeration of a world-wide law. Following up the matter to a logical conclusion, it is obvious that, strictly speaking, all animals are by their nature parasitic ; they are utterly and entirely dependent upon the plants that provide their food.

Parasitic and Saprophytic Fungi.

Fungi are very simple in structure and are characterised by the complete absence of chlorophyll. It is this lack that determines their mode of life. If they are not *parasites*, getting their food from a living host, then they are *saprophytes*, living either upon a dead, or upon a non-living, organic substance. The plant-body of a fungus is usually a much-spreading, much-branching, and interweaving mass, of delicate, colourless threads, or *hyphæ*. The whole mass of threads is the *mycelium*.

Among fungal parasites are the various Mildews, the Wheat Smuts, the Wheat Rust, and the diseases of salmon, trout, goldfish, and silkworm.

In these parasitic and saprophytic plants, as in parasitic animals, an outstanding characteristic is the enormous number of reproductive bodies.

Mildews.

Mildews are fungi that live upon the leaves and fruits of Flowering Plants. Their branching hyphæ spread in all directions over the leaves of many plants. They account for the cobwebby film often seen on the leaves of Poplar, Hop, Gooseberry, and Grape Vine, and on the fruits of Apricots and Peaches.

At intervals transverse walls cross the threads. As these do not divide the plant into actual cells, a hypha is not strictly comparable to a filament of Spirogyra. Each segment of a hypha contains many small nuclei.

The Grape Vine mildew was first recognised in England in 1845. It has since been encountered in all grape-growing countries. Where Vines are grown on a large scale they are regularly sprayed, in the spring, with a solution of copper sulphate, to prevent the fungal attack.

In all the Mildews the mycelium that spreads over the leaves gives rise to certain thicker branches, *haustoria*. These penetrate into the tissues of the leaf, either making their way through a stoma or, as the result of enzyme secretion, actually piercing the epidermis. Thus the parasite gets a firm hold on the host and absorbs the food that the leaves are making.

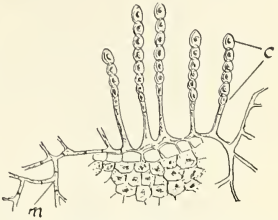


Fig. 278.—Transverse section of leaf of Hop, showing the spreading mycelium of the mildew (*m.*) and the chains of conidia (*c.*).

At this stage some of the hyphæ stand erect, at right angles to the leaf. Just behind the tip of each hypha a constriction occurs, which results in the nipping off of a round, nucleated body, or *conidium*. This is an asexual reproductive body. Succeeding constrictions take place rapidly and the conidia appear in chains (Fig. 278).

Another method of reproduction depends upon "fructifications" which result from a complicated coiling of hyphæ and of nuclear-division. They are seen as minute yellowish specks on Gooseberry fruits and leaves, and as dark spots on the Hop and Poplar. Spores, somewhat similar to those that develop on the under surface of fern fronds, are formed within the fructifications, and are a second prolific means of disseminating the disease (Fig. 279).

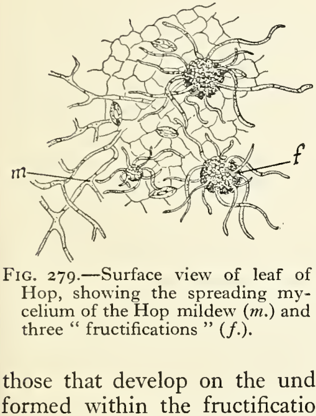


Fig. 279.—Surface view of leaf of Hop, showing the spreading mycelium of the Hop mildew (*m.*) and three "fructifications" (*f.*).

The conidia and spores germinate, putting out germ-tubes which penetrate the tissue of the host. The whole history is then repeated.

Some parasites, having killed their hosts, live upon them for a time saprophytically.

Other fungi are saprophytes only, and of this class the Moulds are common types.

The reproductive bodies of all Mildews and Moulds are extraordinarily resistant. Also they are very light. These facts account for their perpetual presence in the air. To get a good cultivation of Mucor (a Mould) it is only necessary to put a little damp bread under a bell-jar and wait.

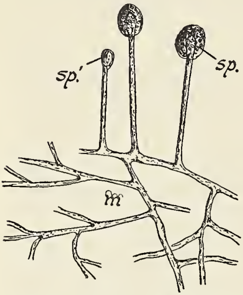


Fig. 280.—Mucor, grown on bread. *m.*, mycelium; *sp.*, sporangium; sp^1., immature sporangium.

Mucor.

Probably in five days' time the Mould is growing on the bread. It may result from spores that were on the bread before it was taken for experiment, or it may be growing from spores that were in the limited supply of air under the bell-jar.

The beautiful, delicate white mycelium grows very quickly. In this case there are no cross-walls, so that the plant is a hollow, branching, slender tube containing numerous small nuclei (Fig. 280).

Some of the branches of the mycelium stand erect. Each of these ends in a black, round head which is delimited by a wall. This is a *sporangium* and contains a number of spores.

In Mucor, in very rare cases, and only if conditions are adverse, the plant resorts to sexual multiplication.

Two hyphæ, apparently from different plants, meet at the tips. A transverse wall behind each tip cuts off a little hyphal area. The walls at the tips break down and the contents of the two areas fuse, forming a zygote (Fig. 281).

This method of conjugation resembles superficially that which occurs in Spirogyra (p. 21).

The wall of the zygote becomes many-layered, rough, and very resistant. In the protoplasm of the zygote a large quantity of food is stored up, principally as oil which accumulates in drops. Thus the zygote is equipped for a long resting period.

It may be carried in the air to another host where good conditions prevail. Its germination consists in putting out one long hypha which bears at its tip one sporangium, in all respects like those borne by the mycelial weft.

The bursting of this one sporangium sets free numbers of spores. They germinate in a suitable medium and the whole life-history is repeated.

Mucor grows on many organic substances, on bread, jam, and on the leather of boots in a damp cupboard.

When it is growing on jam it is interesting to notice that the mycelium always forms at the top of the jam-jar, just underneath the paper cover. This indicates its imperative need for oxygen; a need that is shared by the great majority of fungal growths.

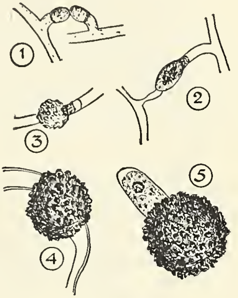


Fig. 281.—Sexual reproduction of Mucor. 1. The meeting of two hyphæ. 2. The fusion of the contents of the tips. 3. A young zygote. 4. A mature zygote. 5. A zygote germinating.

When Mucor has grown for some little time under the bell-jar, other organisms grow on the bread.

Two other Moulds appear, namely, Penicillium and Eurotium. These in their morphology and method of reproduction resemble the Mildews. It is in their habit of life that they differ. Penicillium is the blue-green Mould of Stilton and Gorgonzola cheeses.

Yellow patches and red spots upon the bread are due to the action of Bacteria. Similar red spots are often seen on cheese, looking as though blood from a cut finger had dropped upon it.

Fungal parasites and saprophytes do not grow only on other plants; many of them live only on animal hosts.

Species of Saprolegnia are a grave menace in Trout- and Salmon-rearing stations. The fungal hyphæ often enter through the gill-slits and, blocking the passages, make respiration impossible (p. 70).

Fungi on Animal Hosts.

The hyphæ make their way, too, through the skin, particularly if there is any abrasion. The fungus may then ramify throughout the tissues, feeding, by the secretion of enzymes, on the body of its host.

It is just a moot point whether this is the cause of the heavy mortality among young Salmon. It may be that the fish are first attacked by bacteria, and that it is not until they are in this weakened condition that Saprolegnia preys upon them. In either case the fungus is the immediate cause of their death.

Ringworm is a fungal parasite that grows below the mammalian skin. All the fungal threads grow out equally from a common centre. When the central parts die away only the ring of the circumference is left.

This centrifugal mode of growth is also the explanation of the " fairy rings " of open woods and meadows.

CHAPTER XXXI

DISTINCTION BETWEEN PLANTS AND ANIMALS

It was the great French biologist, Lamarck, who died in 1829, who first proposed the term *Biology* for the Science of Living Things.

As living things are either Animals or Plants, biology must perforce concern itself with the study of these ; and this not in any limited sense, but from the widest possible standpoint. The science must deal not only with the complexities and inter-relations of plants, and with the complexities and inter-relations of animals, but, further, with the inter-relations of animals and plants ; not only, too, with their dependence one upon another, but with the distinctions between these two great classes of living things.

In the higher forms of life there are certain broad distinctions between Plants and Animals. Among lowly organisms it is sometimes difficult to draw the dividing line. Some, on the border of two kingdoms, as it were, are commonly referred to as plant-animals. This is the case with Euglena, Volvox, and Hydra viridis.

Movement.

By the uninitiated, *movement*, that is, *progression*, would probably be cited as a fundamental quality, marking off an animal from a plant. In the most highly organised forms this distinction holds good. It breaks down when the simplest forms are considered. Chlamydomonas, the plant, moves actively. Hydra, the animal, is stationary for the greater part of its life.

Structure.

The elaborate digestive, nervous, and respiratory systems of the higher animals have no counterpart in the most highly developed plants. This cannot, however, be regarded as a fundamental distinction, for a lowly animal, like a lowly plant, Amœba equally with Chlamydomonas, carries on all physiological activities within the compass of a single cell.

Photosynthesis.

The power of building up organic food is essentially a characteristic of plants. But as it depends upon the presence of chlorophyll, the Mushroom, beyond doubt a plant, is no more capable of working up its own organic food compounds than is the Fish, the Frog, or the Rabbit. The fungi are in exactly the same state of dependence as are animals.

Method of Feeding.

Plants take in their food constituents in fluid form, either as liquid or gas. This is the typical *holophytic* method of feeding. Animals, on the other hand, feed *holozoically*, engulfing or swallowing solid particles of food. This does seem a more fundamental distinction than any of the foregoing. But even this is no safe argument, for it is a debatable point whether Euglena really lashes solid food into its gullet, or no. And quite certainly Euglena, claimed by the zoologist and ceded by the botanist, does build up a form of starch, paramylum, by virtue of the chlorophyll granules that are an intimate part of its structure.

Nitrogenous Waste.

Possibly the one unimpeachable distinction between plant and animal is the nature of the waste material excreted in the two cases. Urea is the typical secretion of the animal body. Even in the lowly Amœba it is claimed that uric acid is discharged from the contractile vacuole (p. 7). No such claim has been made with regard to the similar contractile vacuoles of Chlamydomonas.

It is because of the common ancestry of plants and animals that there is this impossibility of drawing a hard-and-fast line between them. The more primitive types closely resemble the common ancestor and, naturally, each other. In the divergent types individual characteristics are pronounced.

Possibly, the whole question of feeding is, in the last analysis, responsible for some of the divergences. This is certainly so as far as movement is concerned. Plants have no need to move. The air shifts and fresh supplies of carbon dioxide are brought within their reach. Decay, followed by bacterial action, renews the food content of the soil. Animals, on the other hand, very quickly exhaust the supply of food in one particular area. A tethered goat must be moved frequently. Cows, proverbially, need new pastures.

CHAPTER XXXII

THE INTER-RELATION OF PLANTS AND ANIMALS

The lives of Plants and Animals which, perhaps, at first sight seem so entirely separate and individual are, actually, most intimately connected. The connection varies both as regards degree and endurance in time.

When two individuals live together in such intimate connection as to appear one, their union is known as *symbiosis*.

Symbiosis. Apparently each member of the union benefits by the close partnership.

Among lowly plants a very perfect case of symbiosis is seen in Lichens. A Lichen is a community of Algæ and Fungi living in such complete union that a Lichen expanse appears as one plant.

Such a union may occur between plants that differ widely in complexity. The investment of Beech roots with a mycorrhiza-forming Fungus affords an example of such a partnership (p. 244).

Just as there may be symbiotic union between plant and plant, so may there also be symbiosis between two animals.

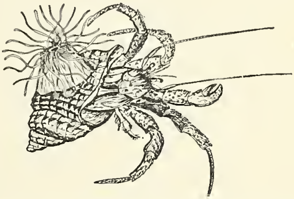


Fig. 282.—Hermit Crab occupying a Whelk shell, to which a Sea Anemone is fixed.

The Sea Anemone is a Cœlenterate, closely related to Hydra. There are certain Sea Anemones that fix themselves firmly to the shells of Hermit Crabs (Fig. 282). As the Crab moves the Anemone is carried from place to place. In all probability it is thus brought into regions of more plentiful food. Certainly the Crab benefits because it is difficult for its enemies to distinguish it, overshadowed as it is by the body and tentacles of the Anemone it carries.

Another Cœlenterate, *Hydra viridis* (p. 30), shelters numbers of unicellular Algæ. Here is a case of symbiosis not between plant and plant, nor between animal and animal, but actually between animal and plant. The Algæ are within the animal cells and undoubtedly help in the nutrition of Hydra by carrying on the work of photosynthesis.

There are, however, more fleeting relationships than this between animals and plants. A sort of temporary symbiosis may obtain.

In pollination the association of plant and animal is usually very fleeting, but it is certainly advantageous. The insect is fed, and through its agency the plant benefits, for pollination is followed by fertilisation.

In some few cases of seed-dispersal, too, there is a certain gain to the animal. The Ant is better off for harvesting those seeds whose caruncles are nutritious (p. 382). The seeds benefit by germinating away from their place of origin. Generally, however, in cases of dispersal the animal is an unconscious, or even unwilling, agent—possibly suffering inconvenience because of the fruits that have attached themselves to some part of his body.

Plants and animals gain mutually as a result of the gaseous interchange between the individual and the environment. If plants lived in a world of their own they could maintain a satisfactory balance of gases for their physiological needs ; carbon dioxide is, however, made more readily available for them because of animal respiration. The animal gains greatly by the volume of oxygen returned to the environment by plants in photo-synthesis.

The balance of advantage is decidedly on the side of the animals. No animal can live independently of plants, unless it be some primitive organism like Euglena, which contains chlorophyll, and therefore reaches a degree of independence.

Animals are unable to act upon the inorganic constituents of earth and air and build up organic compounds ; but the plant can, in its green tissues, carry on such analytical an synthetic processes that, from these inorganic substances, complex foods result. An animal surrounded by such substances is helpless. It is entirely dependent upon the plant for food.

In our day, more than ever before, the dependence of animal-life upon plant-life is realised. Without vitamins our physiological processes would go entirely astray and our whole development would suffer. They are absolutely indispensable to normal animal life. For their formation they are dependent upon light. It is in plant-tissues, through the agency of light, that these all-important controlling forces are produced.

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